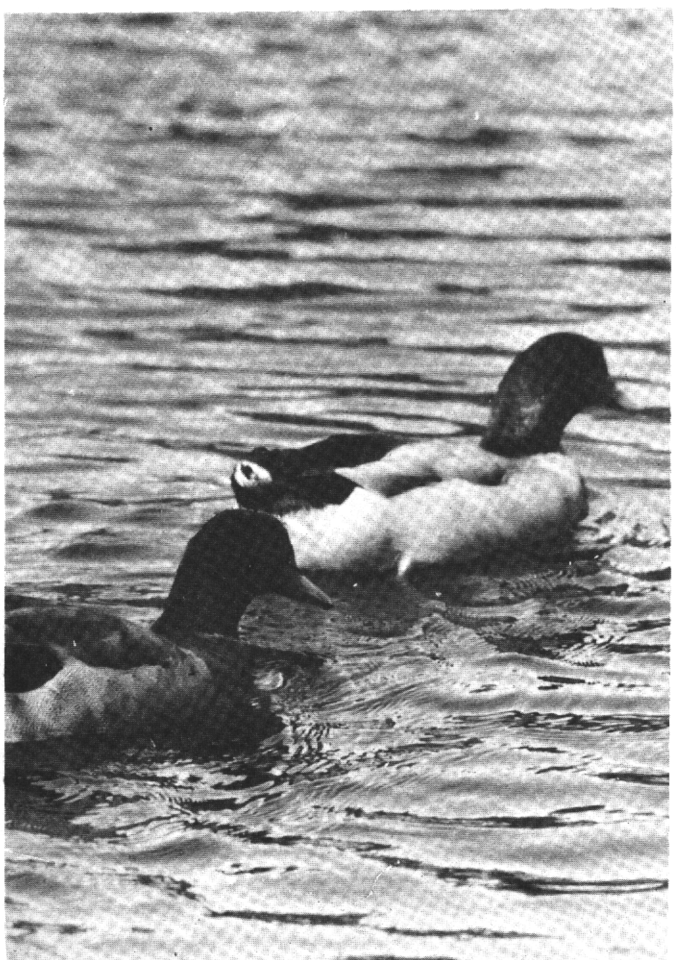
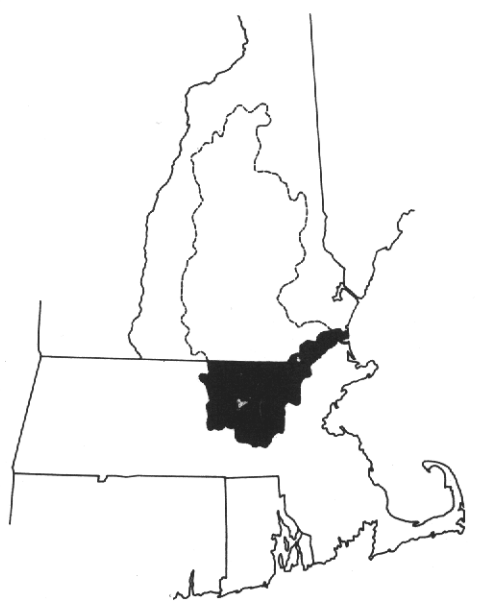
MERRIMACK WASTEWATER MANAGEMENT

key to a clean river



APPENDIX IV-B

BIOLOGICAL IMPACTS
Volume 1



NORTHEASTERN UNITED STATES WATER SUPPLY STUDY

NOVEMBER 1974

MERRIMACK WASTEWATER MANAGEMENT
INDEX TO REPORT VOLUMES

MERRIMACK WASTEWATER MANAGEMENT

(KEY TO A CLEAN RIVER)

APPENDIX IV-B

ENVIRONMENTAL CONDITIONS IN THE MERRIMACK RIVER WATERSHED, MASSACHUSETTS,

and Probable Impacts of Wastewater Management Alternatives

(Volume 1)

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SUMMARY

INTRODUCTION

More than 130,000,000 gallons of raw and partially treated municipal and industrial wastewater flow into the Merrimack River every day. While this quantity of wastewater constitutes only 2.5% of the river's daily flow averaged on a yearly basis, impacts of materials carried in the wastewater to receiving waters have been significant. These impacts are enhanced at various times throughout the year by additional pollutants contributed by storm and meltwater runoff from urban areas. Although the existing treatment facilities treat some of the total wastewater flowing to the river, the capacities of these facilities are too small to handle both stormwater and wastewater flows. This often results in inadequate treatment of wastewater with untreated and diluted wastewater being discharged directly to the Merrimack River or one of the major tributary streams.

Contained within the wastewater are numerous suspended and dissolved materials often termed pollutants. For purposes of this discussion, pollutants are defined as materials introduced into a system in amounts which impeded the functioning of the natural biological community. These constituents often fall into two categories; non-degradable and biodegradable. Non-degradable pollutants include materials which either do not degrade at all or which do so very slowly, by natural biological and chemical processes. Biodegradable materials are those which are naturally and fairly quickly decomposed and recycled through natural systems. The net effect of both non-degradable and biodegradable pollutants to the environment is to alter natural biological processes in aquatic and terrestrial environments to the favor of specific types of organisms. Frequently, an environment suitable for one species is altered such that the organisms can no longer survive in the new conditions or does so very poorly. Reduction of species sensitive to pollution enables other species of organism to increase in numbers and spacial extent filling the "void" or "niches" left through elimination of some kinds of organisms. Discharging partially or untreated municipal and industrial wastewater to terrestrial and aquatic ecosystems can substantially alter environmental conditions to favor specific organisms, which are often "less desirable" over organisms valued more for their economic or recreational uses.

To assess environmental impacts or environmental changes resulting from the implementation of any proposed wastewater treatment facilities, specific aquatic and terrestrial data defining ecological conditions in the Merrimack River Basin in Massachusetts were needed. Data from state and Federal agencies and environmental groups were collected and supplemented by additional information collected at 13 aquatic sampling stations and 18 terrestrial sites within the Merrimack River Basin. These data described water quality in the Merrimack, Sudbury, Assabet, Squanacook and Concord Rivers, indicated relative numbers of benthic organisms, aquatic plants and fish within these streams. Analysis of the data showed stream water quality was such that pollution intolerant organisms were either not present or found only in small numbers in the Merrimack River main stream and major tributaries, while faculative and pollution tolerant organisms predominated. Presence of predominately pollution tolerant organisms were indicative of the stressed aquatic environments generally found throughout the Massachusetts portion of the Merrimack Basin.

Terrestrial sites in the Merrimack River Basin were described as to soil characteristics, aspect and seasonal flora and fauna. These data were used as the basis from which to evaluate impacts of proposed wastewater treatment alternatives to terrestrial environments. Impact to the flora and fauna at each site were generally discussed in relation to proposed treatment alternatives.

Initially, 36 wastewater parameters or "pollutants" were listed and attempts made to assess all their impacts upon aquatic and terrestrial ecosystems. To achieve reasonable assessment of environmental impacts, the 36 parameters were arranged into "A" and "B" list of pollutants. The "A" list of pollutants included those which we were more knowledgeable concerning chemical reactions, organisms response, and movement through and effect upon several trophic levels of the food chain. The "B" list of water quality parameters are those for which impacts associated with specific organisms in terms of acute and chronic lethal concentrations have been studied. However, our understanding of these parameters is limited. Major emphasis was placed upon anticipated effects of parameters in the "A" list in the assessment of the impacts of wastewater management alternatives. These parameters included nitrogen, phosphorous, organic matter and oxygen demanding wastes, while the "B" list included toxic organic chemicals and heavy metals. An attempt was made to quantify the "B" list of parameters for wastewaters discharged to terrestrial environment and to compare these levels against EPA criteria for potable waters and aquatic life, irrigation waters and waters used for industrial purposes. Criteria set by the Food and Drug Administration

(FDA) were useful when harmful materials were discharged and accumulation within the human food chain was believed possible.

Abiotic changes in the environment induced either by nature or man initiate and influence biotic processes. For example, the primary producers (phytoplankton and aquatic vascular plants) under conditions suited for growth can, with increased nutrients levels resultant from discharging raw or partially treated wastewaters, grow to nuisance levels of abundance. Rapid growth of primary producers may exceed ability of grazing organisms to keep up with the increasing production of plant material in the aquatic environment. This in turn results in the decomposition of excess plant material by decomposer organisms, bacteria and fungis which will reduce instream oxygen levels, which produce stresses on sensitive organisms such as gamefish or their food organisms in the aquatic communities. Toxic materials also present in wastewater effluent acting alone or in conjunction with lower dissolved oxygen levels can actually kill or drive off organisms considered indicative of a healthy aquatic ecosystem.

Since abiotic factors differentially affect the various members of the biotic community, community structure will be altered. Where biodegradable or non-degradable constituents are present in detrimental quantities, the resultant community will generally support a smaller number of species but in greater abundance. This type of "degraded" community structure was evident in the biological survey of the Merrimack River watershed. Fortunately, river systems are capable of "recovery" once proper wastewater management removes or reduces the discharged harmful materials. Once water quality has been upgraded, biological conditions could be expected to evolve toward a more healthy, diverse biotic community.

Similarly, changes in abiotic factors in terrestrial environments will differentially affect various components of the terrestrial ecosystem which may eliminate sensitive organisms and encourage more tolerant organisms in response to the environmental changes. Unlike aquatic ecosystems, specifically river systems, which are continually flushed, inputs of wastewater constituents to terrestrial environments can accumulate. In the short-term, inputs to terrestrial systems may prove insignificant, assuming adequate pretreatment of industrial and municipal wastewater. However, chronic exposure to heavy metals or organic constituents could reduce species diversity and productivity where inadequate wastewater treatment prevails prior to land application of effluents. As our scientific and technological understanding of the movement and cycling of various wastewater constituents increases, especially how heavy metals move through the food chain, land application systems may become a more viable alternative to wastewater treatment. However, present understanding of the fixation and availability of many wastewater constituents is in the preliminary stage of definition. For this reason, toxic constituents such as heavy metals and specific organics presently in wastewater effluents applied to the land, were assumed to be in those concentrations specified by EPA Water Quality Criteria for Irrigation Waters.

Handling of sludge from various wastewater treatment facilities and processes remains an important consideration in any regional wastewater management alternative, since heavy metals and specific organics tend to accumulate in sludges derived from various conditional treatment processes. The assumption was made that under current State-EPA guidelines, industrial wastewaters would be made compatible with the biological processes of conventional biological secondary treatment facilities. Because of the sensitivity of organisms involved in the biological processes to heavy metal and toxic organic chemical, some industrial wastewater pretreatment is essential. However, sludges derived from these industrial treatment facilities will probably contain considerable concentrations of heavy metals and toxic organics. Sludge management of industrial sludges as well as those from conventional and advanced wastewater treatment facilities will be by incineration and landfill. This was believed to result in lesser degree of environmental degradation. Disposal of incineration residue or treatment process sludges in landfills does not remove the possibility of a potential environmental hazard rather the problem is concentrated at a local point.

Impacts of Wastewater Management Alternatives

Each wastewater management alternative was evaluated as to its impact to aquatic ecosystems in four major categories: (1) algal productivity; (2) aquatic macrophyte response; (3) invertebrate response; and (4) fish population response within the study area. Each category summarizes many environmental factors affecting many species of organisms in response to water quality changes.

Implementation Program

Implementation of secondary treatment (State Implementation Plan) to meet the 1977 water quality goals within the study area should remove some oxygen demanding materials and suspended solids, which are presently being discharged in wastewaters. Through secondary treatment, biological transformations of many wastewater constituents could be anticipated; specifically oxidation of organic materials, and removal of some nitrogen, phosphorous and other elements which are associated with settleable solids. The nature of the secondary treatment processes fails to remove many wastewater constituents such as heavy metals, refractory organics, soluable nitrogen and phosphous fractions. Therefore, adverse environmental impacts could develop where volumes of effluent discharged are proportionately high with regards to the size of the receiving waters and concentration of specific constituents. This is important where large effluent volumes are discharged to the Concord River and various locals on the Merrimack mainstem. Primary productivity within the Concord River was expected to remain about the same, with algae and macrophytes reaching some sort of equilibrium with their nutrient-rich environment. Effluents from regional secondary facilities at Lowell and Lawrence and in the estuary regions of the Merrimack River mainstem should increase primary productivity due to increased nutrient inputs resulting from discharge of larger effluent volumes to the Merrimack mainstem. In both the Concord and the Merrimack Rivers, substantial positive changes within invertebrate populations were not anticipated in the aquatic community. This is due to the fact that toxic materials, structural organics and heavy metals were not substantially reduced. Organic materials removed in secondary treatment processes is expected to be resynthesized by natural processes responding to the nutrient's discharge in secondary effluent. Decay of the organic material will affect the dissolved oxygen levels in the receiving streams which will hinder the potential establishment of pollution sensitive invertebrate organisms. This in effect limits increased diversity and stability of the benthic communities. Heavy metals not removed in the secondary treatment processes will affect the physiological or life processes of invertebrate organisms, further limiting their recovery in the receiving streams. Fish populations are not expected to substantially change within the Concord River, due to the concentration of ammonia, chloramines, chlorine and dissolved oxygen levels in the secondary effluent discharged to the Concord River. Chronic toxicities of heavy metals and biomagnification of heavy metals were anticipated within the food chain of finfish in the Concord River. Similarly, fish populations within the Merrimack mainstem are not expected to substantially change by the institution of secondary treatment. Although dissolved oxygen conditions in some areas may improve, changes to "desirable" levels are not expected from the Lowell outfall to the estuary. Modeling water quality impacts of secondary effluent discharged to the Merrimack River within the study area showed secondary treatment would reduce biochemical oxygen demand material within the Merrimack River and correspondingly increase the dissolved oxygen level within the river, however, dissolved oxygen levels would remain less than the 5 mg/l during the 7-day 10-year low flow period. If secondary wastewater treatment facilities oxidized nitrogen present within the wastewater dissolved oxygen levels during low flow periods could be increased to approximately 5 mg/l. Even so, the concentrations of biochemical oxygen demanding material would remain at about 6 mg/l or higher, depending upon rates of primary productivity and decomposition.

Advance Wastewater Treatment Facilities

Implementation of advance wastewater treatment facilities are expected to improve the quality of effluent discharge to receiving waters by reducing nitrogen and phosphorous impacts which can decrease primary productivity. This would prevent resynthesis of organic material which upon decay will exert oxygen demand in the stream. Removal of heavy metals and refractory organics which adversely affect pollution sensitive macro and micro flora and fauna would enhance their re-establishment and hasten the increase of sensitive organisms, presently excluded from the Concord and Merrimack Rivers due to the stress conditions. Flow augmentation in the Concord and Powwow Rivers which act as receiving streams for regional facilities will stabilize streamflows during low flow summer and fall periods. Some toxicities to invertebrates and fish could be anticipated from ammonia and chloramines found within the effluent discharged. However, substantial impacts of these constituents are not anticipated in view of the low effluent concentrations. Environmental impacts of advanced wastewater treatment facilities essentially show a substantial improvement in water quality of the receiving streams particularly where the volume of effluent discharged is small compared to the streamflow volume. Where wastewater management alternatives propose large treatment facilities to gain economy of scale through regionalization, the larger effluent flows discharged to receiving streams tended to offset or neutralize improvements in water quality of the receiving stream. Although larger effluent discharge would provide flow augmentation, particularly in the Concord River, effluents flow would dominate river flow, particularly during low flow periods. In this instance, residual ammonia and residual chlorine concentration in the effluent could approach toxic levels to both invertebrate and fish populations, thus offsetting improvements in water quality and establishment of more sensitive flora and fauna.

Terrestrial Impacts of Water-Oriented Wastewater Treatment Facilities

Implementation of conventional secondary and advance wastewater treatment facilities would have obvious adverse local impacts upon natural terrestrial environments, however, when considered on a regional basis, these impacts would be negligible in extent. Following construction of conveyance lines through natural areas, these disturbed areas would begin anew, the natural succession process towards stable and diverse plant and animal communities. Management of these areas to encourage selected organisms desired for their economic and/or recreational value could be compatible with maintaining the collection and treatment facilities.

Land Application for Advanced Wastewater Treatment

Land treatment methodologies considered for additional wastewater treatment beyond that achieved in conventional biological secondary treatment facility were spray irrigation and rapid infiltration. Each approach uses the soil/biological system to further renovate the secondarily treated wastewater. Since abiotic and biotic processes differed in intensity between various soils, the land treatment method considered and the management procedures utilized were adjusted to the proposed site to insure acceptable renovation and minimize potential adverse environmental impacts.

Environmental impacts envisioned for spray irrigation sites were those associated with an increase soil moisture regime in the application area and disturbance of habitat. Specifically, where forested lands were used for wastewater application, vegetation in these areas could be expected to evolve towards a more hydric community. In agricultural land, some drainage would be needed to maintain an aerobic route zone in order to facilitate plant growth. This was particularly important where corn and other cultivators were considered. Nitrogen and phosphorous within the effluent were not seen to be problematic where plant material was removed from the application site on an annual basis. In these areas, plant uptake, soil fixation of nitrogen and phosphorous, and gaseous loss of nitrogen could account for most nutrient inputs during the year. Some increases in nutrient concentrations in the groundwater might occur after many years of operation; however, these levels should not exceed public health's drinking water standard criteria, if proper management is carried out. In forested areas, where plant material is not removed annually, nutrients added to the application site could increase to a higher equilibrium level eventually resulting in increased leaching potential.

It was assumed that heavy metal concentrations in the effluent applied to the land application areas would meet EPA criteria for irrigation waters to agricultural lands. If these criteria were achieved, heavy metal inputs should not create potential environmental hazards.

However, heavy metal concentrations greater than the EPA criteria, could lend to accumulation in the soil possibly to levels toxic to the crop grown or the organism consuming these crops. Some changes could be anticipated in soil micro-organism populations and diversity in spray irrigation areas in response to increased soil moisture, nutrient availability, soil pH, or increased organic matter and temperature changes. If the soil environment is maintained to provide aerobic conditions, the concentrations of inhibiting substances in the "typical" secondary sewerage effluent were not believed sufficient to induce detrimental effects to the soil ecosystem. Shock loading of inhibitory substances, especially if organic in nature, could have serious consequences to land wastewater management systems. Impact of applied effluent will decrease the rate of soil drying, which in turn decreased the soil-warming rate during the spring period. Decreasing the temperature of the soil essentially restrains the physiological process of soil micro-organisms during this period, however, the overall efficiency of the soil micro-organism system is not anticipated to decrease.

The effects of the land application spray irrigation system upon mammals and birds is expected to be minor. Substantial benefits could be anticipated through a modification of habitat, particularly where forested areas are converted to pasture or forage lands. This would increase cotton tail and deer population in response to the increase open space and greater availability of plant material.

Rapid Infiltration

Unlike the spray irrigation concept which required considerable land area, the areal extent for rapid infiltration is much less since a larger volume of water is applied per unit land area. Therefore, disturbances of terrestrial systems is seen to be significant at the local level but regionally eclogical impacts will probably be much less. Location of rapid infiltration sites along large streams eliminates the potential for increasing salts, nitrogen, phosphorous and organic constituents in the groundwater used for potable waters. These sites are essentially comparable to bank storage in that the wastewater from rapid infiltration sites recharge directly to the stream. The volumes of wastewater effluent for application to proposed rapid infiltration along the Merrimack mainstem should have no significant impact to the receiving stream in terms of dissolved oxygen levels and increased river flow. Flow augmentation is possible where rapid infiltration sites are located on smaller streams. Control of nutrients and other wastewater constituents in the rapid infiltration site is seen as potential problems requiring good overall management of the facility. In the short-term, nutrient uptake through soil fixation and volatization could control most of the nitrogen and phosphorous additions to the application site, however, in the long-term operation, nutrients may begin to move from the application site and enter surface waters.

ENVIRONMENTAL CONDITIONS IN THE MERRIMACK RIVER WATERSHED, MASSACHUSETTS, AND PROBABLE IMPACTS OF WASTEWATER MANAGEMENT ALTERNATIVES

I. OBJECTIVES

A. STATEMENT OF THE PROBLEM

More than 120 million gallons of raw and partially treated, municipal and industrial wastewater flow into the Merrimack River every day. This quantity of wastewater constitutes approximately two and a half percent of the total river flow averaged on a yearly basis. While this may seem to be a reasonably small proportion, it should be borne in mind that the world's oceans would all be freshwater if it were not for a mere three and a half per cent content of dissolved solids. Compounding the problem is the wide fluctuation in river flow volume. During prolonged periods of dry summer weather the wastewater proportion may rise to eighteen percent of the total flow. United States Geological Survey records dating back to 1923, based on the low flow of record, show that wastewater could represent more than 90% of total river flow.

At various times throughout the year, the contribution of wastewater is augmented by storm and meltwater runoff. In urbanized areas this surface runoff is typically channeled from catch basins directly into drains (combined sewers), which also collect and transmit municipal wastes. Capacities of existing wastewater treatment plants, designed for normal domestic flows, are usually too small to handle the combined flows. Thus, treatment processes are bypassed, and the diluted, but untreated, effluent is released directly into the river.

Various kinds of pollutants are discharged into the watershed. Pollutants are defined as materials introduced into a system in amounts that impede the functioning of the "natural" biological community. These fall under two basic categories -- nondegradable and biodegradable (Odum, 1971). Nondegradable pollutants include materials and poisons which either do not degrade at all or do so very slowly; and biodegradable pollutants are ones which are naturally and fairly quickly decomposed in the environment. Representatives of each of these types of pollutants are present in wastewaters of eastern Massachusetts. As a result of this wastewater input, conditions for aquatic life in the river have been degraded. The utility of the river as a suitable environment, particularly for the kinds of fish and other aquatic life desirable for commercial, recreational, and aesthetic purposes, has been impaired, while "undesirable" organisms (either pathogenic or non-pathogenic) have been encouraged.

The designation of non-pathogenic organisms as "desirable" or "undesirable" is fairly subjective. Carp, for example, are generally considered undesirable fish, whereas bass, due to their habits and angling value, are considered desirable. Implicit in the concept of desirability is the fact that so-called "desirable" forms are associated with, and indicative of, a clean environment.

There are plant and animal "indicator" species for both terrestrial and aquatic, and polluted and unpolluted habitats. In response to pollution, certain organisms are either excluded or are given a competitive advantage based on their tolerances to the various materials present. Aquatic organisms sensitive to pollution include caddis flies, may flies and game fish; pollution tolerant organisms include carp, midge larvae and certain algae **(Figure 1)**. When a polluted condition exists, its effects are generally evident throughout the entire aquatic community.

Because river ecosystems are continually flushed, they have the capacity to recover, providing pollution is abated. A proper course of constructive action could reverse the present condition of the deteriorated water quality of the Merrimack River and its tributaries and permit the return of desirable organisms to habitats otherwise unsuitable for them.

B. BACKGROUND AND CHRONOLOGY

In 1971 the U. S. Army Corps of Engineers undertook a series of pilot wastewater management feasibility studies. Five urbanized areas were designated, one of them being the Merrimack River Basin. The resulting study report, entitled: "The Merrimack: Designs for a Clean River", along with its ancillary technical appendices and annexes (five consultants' reports on environmental aspects were included in Annex B), was published in September 1971. Data were examined by professionals representing a broad spectrum of disciplines. Seven alternatives were set forth by which the major wastewater discharges into the Merrimack River and tributaries could be renovated to yield water of "maximum feasible purity". Among the objectives of each alternative was to provide for transmission and treatment of three types of waste: domestic sewage, pretreated industrial waste, and stormwater (up to 2.6 inches of rainfall in six hours).

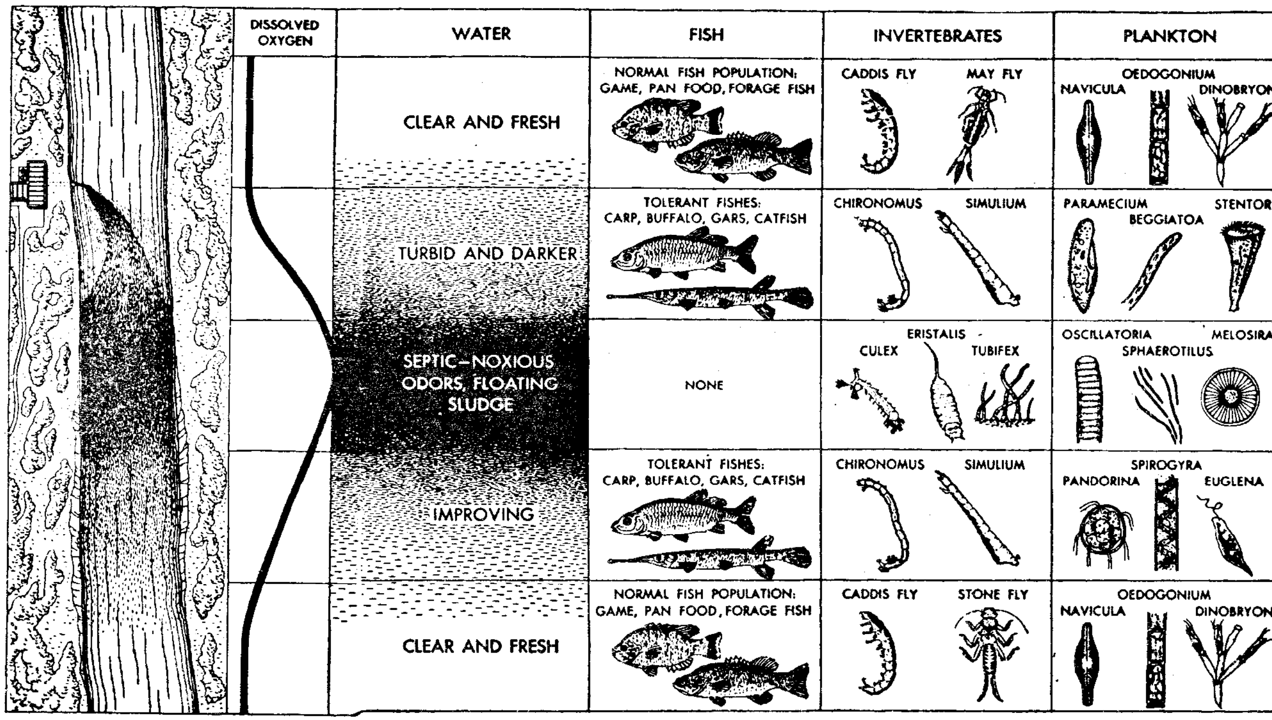


Figure 1. Pollution of a stream with untreated sewage and the subsequent recovery as reflected in changes in the biotic community. As the oxygen dissolved in the water decreases (curve to the left), fishes disappear and only organisms able to obtain oxygen from the surface (as in Culex mosquito larvae) or those which are tolerant of low oxygen concentration are found in zone of maximum organic decomposition. When bacteria have reduced all of the discharged material the stream returns to normal. (After Eliassen, Scientific American, Vol. 186, No. 3, March, 1952).

The strategies utilized included conventional and advanced waste processing plants, land application techniques, and combinations of both. Wastewater treatment within subregions of the river basin was to be integrated geographically, assuming flows projected for the years 1990 and 2020. The ecologically oriented consultants' reports identified in a general way the effects of each of the various strategies of wastewater management on aquatic and terrestrial ecological communities. One report (by Professor E. H. Zube) called for further research activities specifically to develop base line information. Another (Smith & Gilfillan) identified a need for more specific information of physiological and population responses to the presence or absence of various types of pollutants in the Merrimack estuary.

On 2 March 1972 the committee on Public Works of the U. S. Senate passed a resolution directing the Corps of Engineers, in cooperation with the Commonwealth of Massachusetts and the Environmental Protection Agency, to proceed with a wastewater management study of larger scope and depth in the Massachusetts portion of the Merrimack River Basin. The House Public Works Committee produced a similar directive on 14 June 1972. The Corps' present study has since been guided by requirements and policies set forth in the Federal Water Pollution Control Act Ammendments, dated 18 October 1972. Among other things, this document establishes as a national goal "... that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish and wildlife...be achieved by July 1, 1983..., and...that the discharge of pollutants into the navigable water be eliminated by 1985...". The document also sets forth, as national policy, implementation of area wide waste treatment plans "to the extent practical".

C. PRESENT RESEARCH OBJECTIVES

The initial objective of the present investigation was to document, within the time available, the existing conditions with respect to both aquatic and terrestrial flora and fauna, and the chemical quality of waterways and sediments in the designated area (Figure 2). Emphasis was placed on the results of first hand sampling and collecting activities at sites identified in Figure 2. However, because first hand field investigations could not be conducted during the most auspicious season (summer), pertinent data from previous studies conducted within the present study area were incorporated to provide as complete a presentation as feasible under these circumstances. Important data gaps were identified, and the overall completeness and accuracy of available data were assessed.

A subsequent objective was to specify appropriate environmental criteria for use in evaluating the ecological impact of al-

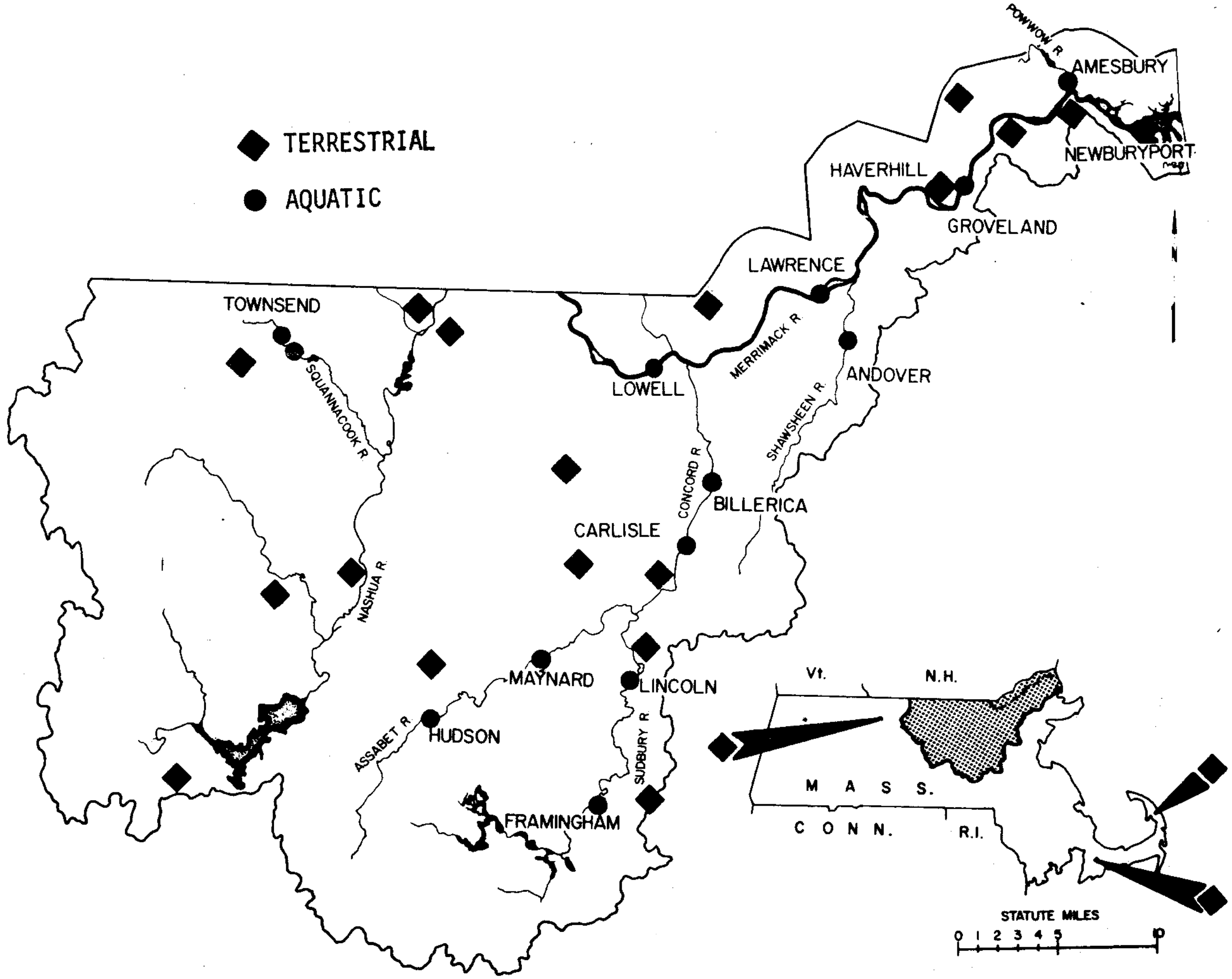


Figure 2. Map of the study area, showing location of terrestrial and aquatic sampling sites established for field investigations, Fall, 1973.

ternative municipal and regional pollution abatement plans which are presently being considered as part of the larger wastewater management study. In developing these criteria, consideration was given to: 1) the need to predict how local aquatic and terrestrial communities will be affected by the implementation of the various wastewater management alternatives; and 2) the need to determine whether any short or long term biological problems will persist after the designed quantity and quality of liquid waste and sludge, discharged upon the land or in the waterways, has been reached. The specified impact criteria were selected from a larger list of parameters and chemical constituents recognized as having some biological impact. Upper or lower limits of tolerance, or growth responses, were considered where such designations were appropriate.

II. GENERAL APPROACH CONSIDERED

The approach we have taken in the present assessment of the Merrimack River resources is one based on the ecosystem, not in the mathematical sense, but in its conceptualization. Thus, we have viewed the Eastern Massachusetts area, and more particularly the Merrimack River watershed, as a complex system of inputs, outputs, and cyclical phenomena, together producing what we perceive as today's "environment". Physical and chemical "inputs" are fed into the system at various points in time and space -- a change in the kind and amount of each input causing a sometimes dramatic, often-times subtle response in the environment. As the study develops, we deal with smaller and smaller "systems" to the point where ultimately, only singular land entities and point-source aquatic discharges must be reckoned within the wastewater evaluations.

That part of the planet Earth in which living forms are active is called the biosphere or ecosphere. It is characterized chiefly by the availability of substantial quantities of water and an abundant supply of energy from an external source (ultimately the sun). Solar energy enters the biotic component of the system through photosynthetic action of chlorophyll bearing organisms (some bacteria, all algae and higher plants) collectively termed primary producers. Beyond the primary producers there are two consumer food chains (Figure 3). One chain begins with the grazing or browsing animals (herbivores) and continues on to successively higher trophic levels of predatory animals. The other consists of organisms of decomposition or decay. These are basically primitive forms (fungi, bacteria, and various other microbes) which derive their energy from the breakdown of dead organic matter. The two chains function side by side and frequently overlap, in that products from one chain may be transferred to the other. Energy is lost at each trophic level from the reception of the sun's energy to the last step of decay. Figure 4 illustrates schematically the stepwise decrease in energy transfer through the trophic chain.

When functioning properly the biosphere is in a state of dynamic equilibrium, in which energy and matter constantly move through the system without appreciably disrupting the status quo or steady state conditions. Except for energy, all other essentials for maintaining life processes are cycled. In the water cycle, for example, evaporation from water bodies is greater than the direct return by precipitation. The reverse is true on land. The ocean deficit and land surplus is rectified by runoff return from streams.

Differences between terrestrial and aquatic ecosystems are profound. On land, virtually all primary producers are attached or closely associated with the substrate (soil). In the aquatic

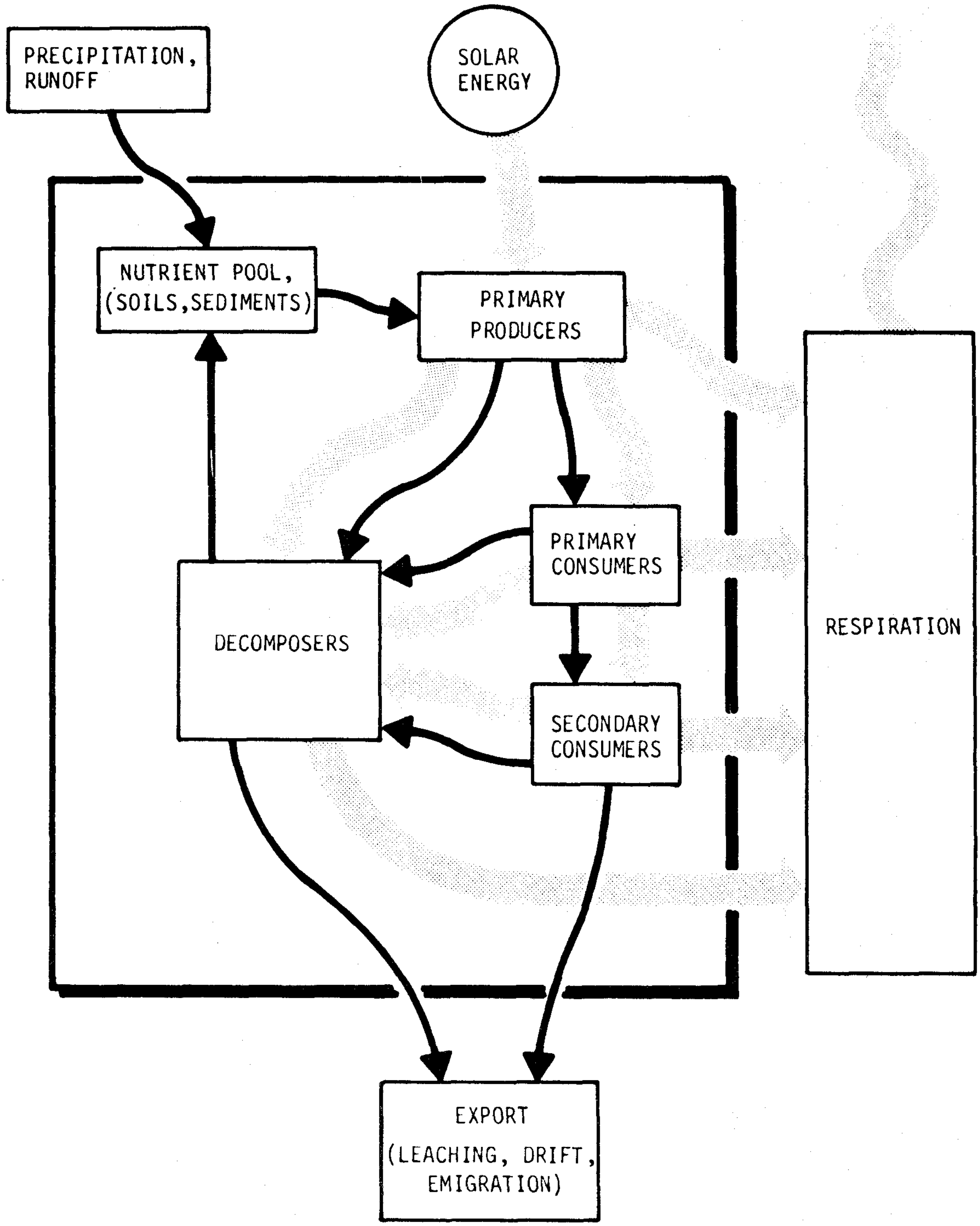


Figure 3. Schematic diagram of energy and nutrient relationships in an ecosystem.

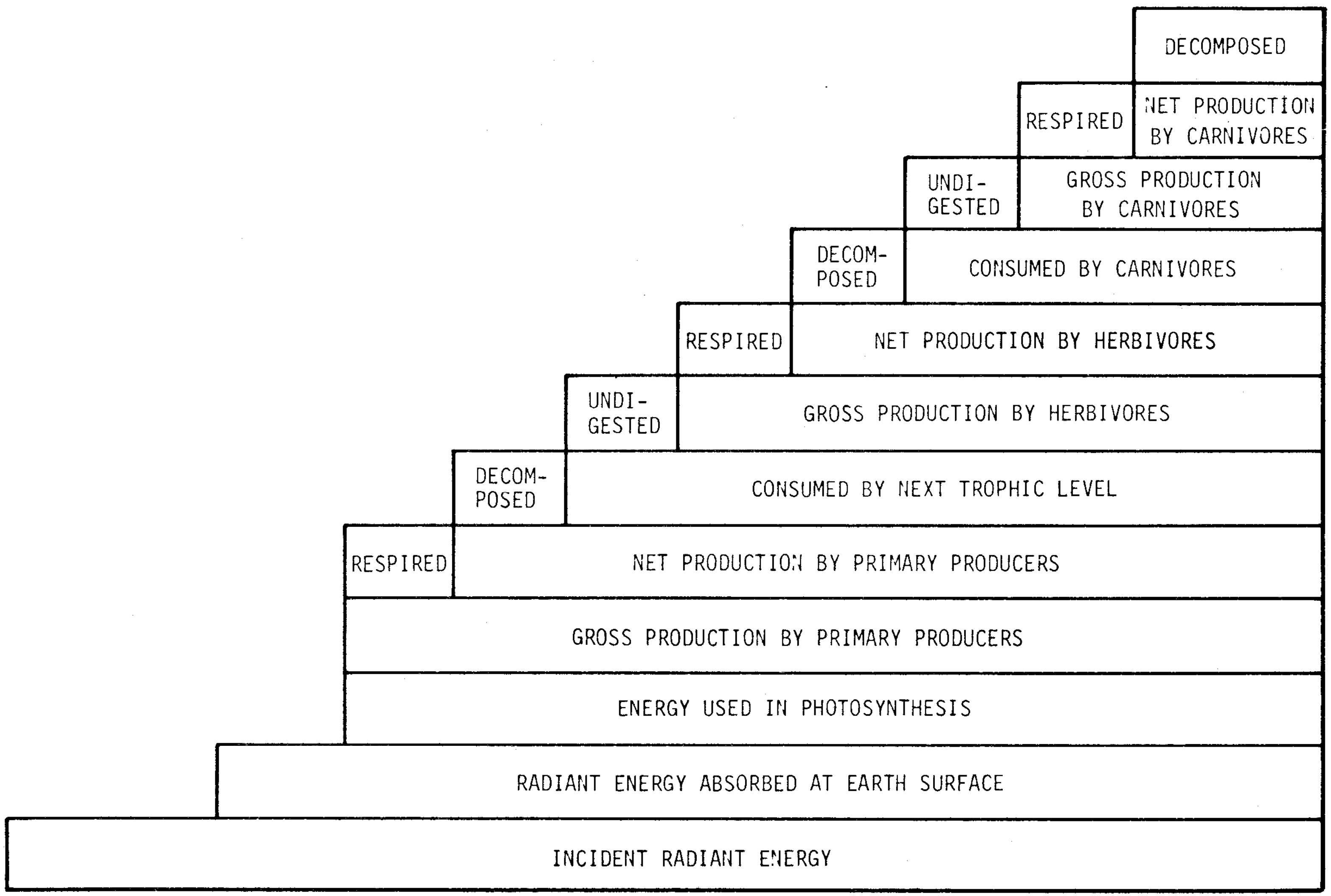


Figure 4. Schematic representation of energy utilization by an ecosystem.

environment, since light penetrates only a short distance, the bulk of primary production (by the phytoplankton) takes place very close to the water surface, removed from the sediments (or substrate) where much of the essentials for life are stored. Most organisms associated with sediments in the aquatic environments are consumers rather than primary producers. On land the consumer biomass is very small compared to the biomass of photosynthetic plants. In the aquatic environment the biomass of consumer organisms is surpassed by the biomass of phytoplankton. The tiny aquatic primary producers support the animal biomass through rapid division and growth.

In terrestrial ecosystems recycling of materials essential for life is tightly controlled, especially in mature forest growth. Most land plants have the capacity to retain (store) essential organic materials (in leaves, fruits, stems, etc.). Inorganic salts are also ionically bound to the vast network of root hairs. In the aquatic environment, however, cycling of many materials is intermittent and sometimes not completed. Availability of the essential nutrients which accumulate in the bottom sediments depends on fortuitous patterns of advection (e.g. upwelling) to bring the materials into the sunlit surface layers where they can be assimilated by phytoplankton and recycled. Consequently, the store of undecomposed and decaying matter under water is characteristically proportionately larger than on land. For complete breakdown and utilization of undecomposed material, oxygen is required. Under certain conditions organisms in the decay chain exhaust the supply of oxygen. In the absence of oxygen, decomposition is incomplete, and products of incomplete decay, such as <u>methane</u>, <u>cyanides</u>, and <u>sulfides</u> build up. Vital connections between the decay chain and the animal consumer chain are reduced or broken and ecosystem integrity is lost. Aquatic ecosystems are more susceptible to the above sequence of events than terrestrial ecosystems, particularly since molecular oxygen (O_2) is only about one-fortieth as concentrated in aerated water as in air.

Due at least in part to under utilization of sediment resources, the aquatic environment is vulnerable to <u>ecological succession</u>, by which the biosphere advances or develops toward more stable (controlled), self regulating communities. Succession progresses through a series of developmental stages (<u>seres</u>). In the absence of natural catastrophic intervention (e.g., glaciation, sea level rise) successional pressure is on the conversion from aquatic to terrestrial systems, not vice versa. When the flow of energy and other essentials is completely open and "once-through", as in freely flowing streams, the successional sequence does not apply. Impounded waters, however, "age" at varying rates, depending in particular on the rate of input of organic and other life essential materials (a process called <u>eutrophication</u>). Development of a terrestrial system from an aquatic system begins with submerged vegetation and continues (seral stages: floating leaved, emergent, saturated soil, sedge-meadow, thicket, moist soil, brush land, fringing woodland) until a mature community evolves consistent with edaphic characteristics (topography, soil characteristics, water supply) and climatic factors. A parallel successional sequence occurs in the progression from barren ground to climax growth. Freshwater aquatic environments are in reality a very scarce resource. The world's freshwater comprises only three percent of the total supply; three quarters of it is in the form of polar ice and glaciers. Only about two percent of the water in liquid form is found in lakes, rivers and similar smaller bodies of water (the remaining 98 percent is ground water).

When a carefully balanced ecosystem breaks down (as in the example of insufficient oxygen described above) a senescent or dying stage usually ensues. Such occurrences are becoming more frequent in a biosphere increasingly dominated by man's influence. Table 1 compares attributes and tendencies of developing, mature and senescent stages of ecological communities. In the following paragraphs many of the factors which have important roles in community development and destruction are considered.

A. ABIOTIC SUBSTANCES

1. Substances with Physical Impact

Insoluble solid material disturbs the ecosystem by blanketing or covering the energy receiving surfaces of primary producers (such as the leaves of higher plants). It is particularly detrimental in the aquatic environment since light penetration is further reduced from what may already be a critically low level. Turbidity measures the extinction of penetrating light caused by the smaller particles which persist in the water column as suspended solids. Larger and heavier particles settle on the bottom (settleable solids) as organic and inorganic silt. Here they also act as a blanket, inhibiting physical and chemical exchange across the sediment-water interface. Substantial changes in the bottom sediment characteristics, as a result of silting, may devastate certain bottom faunal communities by providing the medium for accumulation of noxious materials, and by clogging the respiratory apparatus (e.g., gills) of aquatic animals. On land the emergence of seedlings may be inhibited by heavy silting.

Physical harm is done by oil through the coating action of oil films. Such films may interfere with gaseous exchange between the organism and its environment. In the aquatic environment the air-water interface is especially vulnerable since oxygen may be prevented from entering the water. The heavier the surface coating and the lighter the water movements, the worse the situation becomes.

TABLE 1. CHARACTERISTIC ATTRIBUTES OF ECOSYSTEM STAGES

(Adapted and modified from Odum, 1971)

ATTRIBUTE	DEVELOPING STAGES	MATURE STAGE	SENESCENT STAGE
Ratio: $\frac{\text{gross production}}{\text{community prod.}}$	greater than one	approximately one	less than one
Ratio: $\frac{\text{gross production}}{\text{standing crop biomass}}$	greater than one	less than one	much less than one
Annual yield (new additions to standing crop)	high	low	low
Food chains	simple, direct grazers predominate	intricate, web like	disrupted
Nutrient resources	internal control loose, high reliance on outside sources	internal control tight, nearly self sufficient	controls breakdown, nutrients released
Species diversity	low	high	very low
Biochemical diversity	low	high	very high
Role of decomposers	minor	major	dominating function
Community structure	loosely organized	well organized	poorly organized
Niche space	broad, loosely defined	narrow, well defined	open to invasion
Competitive pressures	high	low	seldom occur

2. Substances with Chemical Impact

Water is the "universal solvent". Hence nearly all materials which come in contact with the biosphere have a chemical impact, since they dissolve to some degree and thus interact with living tissues. It would be a monumental task to cover all, or even most, of the substances incorporated into ecosystems. Consideration will be given below only to those materials with critical impact on the living components of the ecosystem, especially as regards wastewater management.

Liquid water is an ionic solution and always contains some hydrogen ions, since the water itself can supply them. The degree of hydrogen ion dilution (reverse of concentration) is represented by the term pH. A scale from zero to fourteen is established such that zero represents a concentration fourteen orders of magnitude greater than fourteen. In a terrestrial environment soil moisture may give a reading from pH 3 (very acid) to pH 10 (very alkaline), but most plant communities exist in soil with a moisture pH within a few units of pH 6. The permissible range for aquatic communities is somewhat more restricted. In the marine environment the pH range for living organisms is about 7 to 9. This shift of about two units toward alkaline pH comes about due to the chemical activities of greater amounts of dissolved solids in the ocean.

Carbon compounds are the fuel as well as the building material for life. Photosynthetic organisms create organic compounds by fixing carbon dioxide (CO_2) (see Figure 5). The generalized formula is as follows: $CO_2 + 2H_2A + \text{light} \rightarrow CH_2O + H_2O + 2A + \text{energy}$. The A usually represents oxygen (O), but may also represent sulfur (S), a portion of an organic compound, or even nothing at all (in which case the H_2A becomes molecular hydrogen, H_2). Consumers of organic compounds (including the plants themselves) release the chemically stored energy by combusting or oxidizing the organic molecule. Ultimately this requires oxygen to complete the chain of reactions (release of maximum energy). Oxygen demand is a measure of the quantity of oxygen required to release the energy and decompose the material contained in an aqueous medium. The more undecomposed organics present, the higher is the oxygen demand. In practice the oxygen demand is measured either by oxidizing all of the combustible material in a water sample to CO_2 (Chemical Oxygen Demand, COD), or incubating a sample of the water in specially designed bottles for a given period of time under standardized conditions of bacterial decomposition (Biochemical Oxygen Demand, BOD). BOD has special significance in tracing septic conditions. To the non-public health oriented biologist, however, oxygen demand is less meaningful than other more specific measures of movements of essentials for life through the system. Total content of organic carbon (TOC) may be measured. The activity of the primary producers may be followed by the use of radioactive tracers (e.g. Carbon 14), measurement of chlorophyll *a*

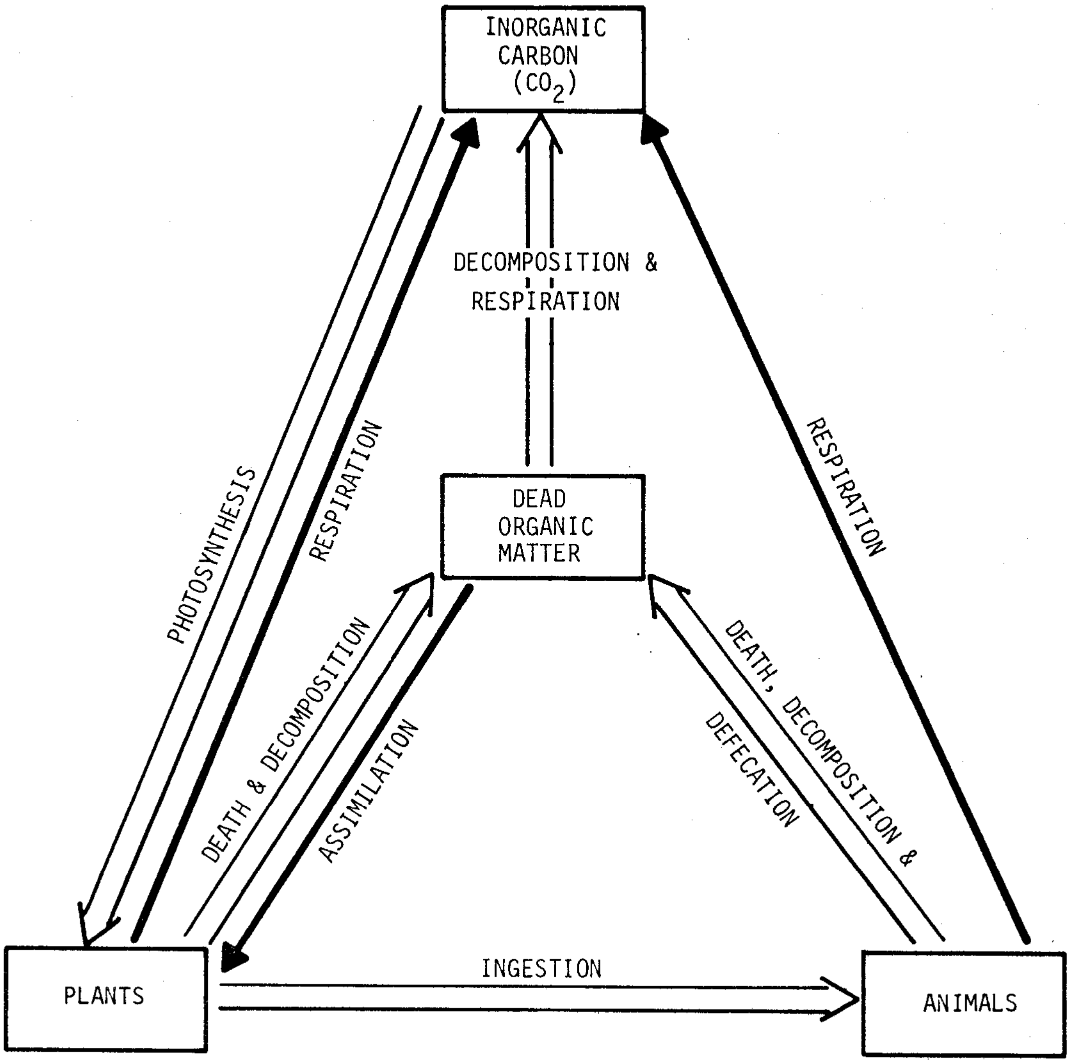


Figure 5. Simplified carbon cycle (broad arrows indicate major loops).

concentration and the light and dark bottle method. All of the measures can be expressed as rates of carbon fixation or energy flow (in kilogram calories per square meter per given period of time). Standing crop biomass is usually expressed as kilogram calories per square meter.

In the aquatic environment inorganic carbon may exist in any of three forms (dissolved CO_2; bicarbonate ion, HCO_3^-; or carbonate ion, $CO_3^=$) depending on pH. In neutral media (pH 7) most of the inorganic carbon is in the form of bicarbonate (CO_2 dominates in acid media and carbonate in alkaline media). In addition to being a readily available source of carbon for carbon fixing organisms, the inorganic carbon system provides a chemical buffering action against changes in pH. To a certain extent, the higher the bicarbonate and carbonate alkalinities, the greater the potential for the medium to assimilate alkaline substances without appreciable shifts in pH. Total alkalinity includes caustic alkalinity (the concentration of hydroxide salts) in addition to bicarbonate and carbonate alkalinities, but hydroxides do not normally contribute substantially to total alkalinity except where alkaline industrial wastes are being released.

Certain organic compounds have a noxious or toxic effect on living organisms. Many of these compounds (such as hydrocarbons and phenols) occur naturally. But, their distribution was limited until the activities of man caused them to be broadcast over wider areas. In addition, manufacturing and other industrial activities have caused exotic organic toxicants to come into ever increasing contact with the bioshpere. The list of known exotic toxicants is long (ranging from abietic acid to xylenol) and growing longer day by day. Specific reactions to these compounds by organisms differ. Many are suspected of having a synergistic effect when contained in various combinations in an aqueous medium (i.e. concentrations too dilute to demonstrate an effect individually may have lethal or sublethal effects when combined concentrations reach a certain level). Another group of toxic organic compounds are the biocides, compounds deliberately formulated by man to kill some form of life considered undesirable. Often biocides are far from specific in their effect. Once having entered the aquatic or terrestrial ecosystem the potential for injury may be carried to desirable organisms. The well documented case of the chlorinated hydrocarbons is one example.

Oxygen appears in many chemical forms and combinations. Certain aspects of its role in the biosphere have been treated above. The content of available oxygen in the aquatic environment is measured as dissolved oxygen (DO). Oxygen content is governed not only by factors affecting exchange with the atmosphere (such as temperature, dissolved solids and turbulent mixing), but by the photosynthetic activity and respiration of plants and animals. With the sun high overhead, in relatively clear waters, production of O_2 exceeds consumption in a thriving phytoplankton population;

DO values are relatively high. By nightfall, however, photosynthesis has ceased; both plants and animals consume the oxygen surplus built up during the day. Just prior to dawn, oxygen values in a lake or slow moving stream are usually at their lowest. The diurnal oxygen curve (generated from continuous or periodic DO readings over a 24-hour period) can be used to quantify the productive activity of a quiet water aquatic comminuty. DO readings approaching zero in the bottom waters indicate a disrupted consumer chain and the build up of products of incomplete decomposition when such readings persist for extended periods of time.

Nitrogen is required in the formulation of proteins by primary producers. Although nitrogen is an abundant element, the bulk of it is in a form (gaseous molecular nitrogen, N_2) unusable by all but a very few forms of life. Nitrogen must be fixed (chemically incorporated into a compound) before it is usable. Until industrial fixation processes were developed, most of the nitrogen fixation was accomplished by terrestrial organisms, often living in close association with higher plants. Marine microorganisms and ionizing phenomena in the atmosphere (lightning, radiation) also contribute to fixation. Terrestrial ecosystems have the capacity to conserve nitrogen in its usable forms.

Primary producer organisms of the aquatic ecosystem (phytoplankton) do not have much storage or holding capacity because of their small size and mass (which allows them to remain longer in the sunlit upper water layers). In the aquatic environment selection has favored mechanisms of quick response to the availability of usable nitrogen (e.g. from products of decomposition in the sediments). Generation times of phytoplankton are very short. Some diatoms, for example can treble their population size in less than 24 hours. Even a seemingly small (few parts per million) increase in usable nitrogen (NH_4 and NO_3) may initiate a bloom under the proper conditions (temperature, light etc). Blooms are periods of high phytoplankton density resulting from intensified reproductive activity; they occur periodically under natural conditions and are usually quite harmless and perhaps even vital to the survival of other forms of aquatic life. Occasionally, however, a bloom develops into a pathological condition. Perhaps a certain species capable of producing toxic substances may dominate temporarily; or an unusually large bloom goes into a sudden decline, levying a heavy burden on the consumer chain. Animal grazers may not reproduce fast enough to crop the phytoplankters before they die. The load of dead and dying plants is shifted solely to the decomposer chain with implications discussed above. Thus, a vitally necessary nutrient has the capacity to choke off the life it sustains, a prospect which has received more and more attention since the advent of large scale manufacture of synthetic fertilizers and concentration of domestic waste into the rather restricted space occupied by freshwater aquatic ecosystems.

The cycle of nitrogen through the biosphere is shown in

Figure 6. Ammonia (NH_3) excreted by animals and produced as an end product of the decay chain is assimilated most readily by plants. However, when released in very large quantities as ammonium hydroxide in industrial wastes it has an immediate toxic effect. Some cold water fish (salmon, trout) are sensitive to substantial accumulations of ammonia in the bottom waters where they normally live, but invertebrates and plants are relatively tolerant. In the absence of ammonia, plants take up nitrate (NO_3^-) which is typically the most abundant usable form of nitrogen in soil or water. Nitrite ($NO_2^=$) is typically a transient form and is least abundant. Concentration of dissolved nitrate is a conventional measure of the nitrogen free of biological control and available for use in producing more living tissue. In a stable, mature ecological community, such as is found in most terrestrial and marine environments, the amount of "excess" nitrogen should be minimal.

Phosphorous is the scarcest commodity of the "macronutrients" (substances required in more than trace amounts). The chief uses of phosphorous are in the skeletal structures of animals (storage) and in the transfer and transport of chemical energy in the form of high energy phosphate bonds (as in adenosine triphosphate, ATP). A simplified scheme of phosphorous cycling is presented in Figure 7. The scarcity of this element requires the same economics to operate as in the case of nitrogen. In fact, phosphorous metabolism appears to be intimately linked to nitrogen. Both elements are scarce, but in non-marine aquatic systems phosphorous is generally considered to be limiting. Living organisms contain enormous quantities of phosphorous compounds compared to normal levels in many types of environment. In the marine environment, for example, the exchange of phosphorous from organism to organism is so rapid that levels of inorganic phosphate (principally as orthophosphate, $PO_4^=$) dissolved in the external medium are often too small to measure with any degree of accuracy with instruments presently available.

Sulfur is required in very small amounts (even less than phosphorous) to form sulfide groups in certain amino acids. Sulfide to sulfide bonds maintain the critical shape of a protein molecule, allowing it to fold and unfold in a manner commensurate with its specific function. Sulfur is available to primary producers in sufficient quantities as sulfate ($SO_4^=$) and sulfide ($S^=$). In the absence of oxygen, sulfur substitutes as an oxidizing agent in organic decomposition. Impounded bottom waters often have considerable stores of sulfide from the accumulation of decomposed living tissue (protein). In aquatic environments where ferrous iron is available most of the sulfide is bound as ferrous sulfide (FeS) which provides much of the black color of reduced muds. Substantial quantities of hydrogen sulfide (H_2S) build up only under dystrophic conditions (disrupted ecosystems and acid bogs). Aquatic organisms are extremely sensitive to even the tiny amounts of H_2S dissolved in water. H_2S can act as an environmental cue in the avoidance of bottom waters where these organisms might die from lack of oxygen.

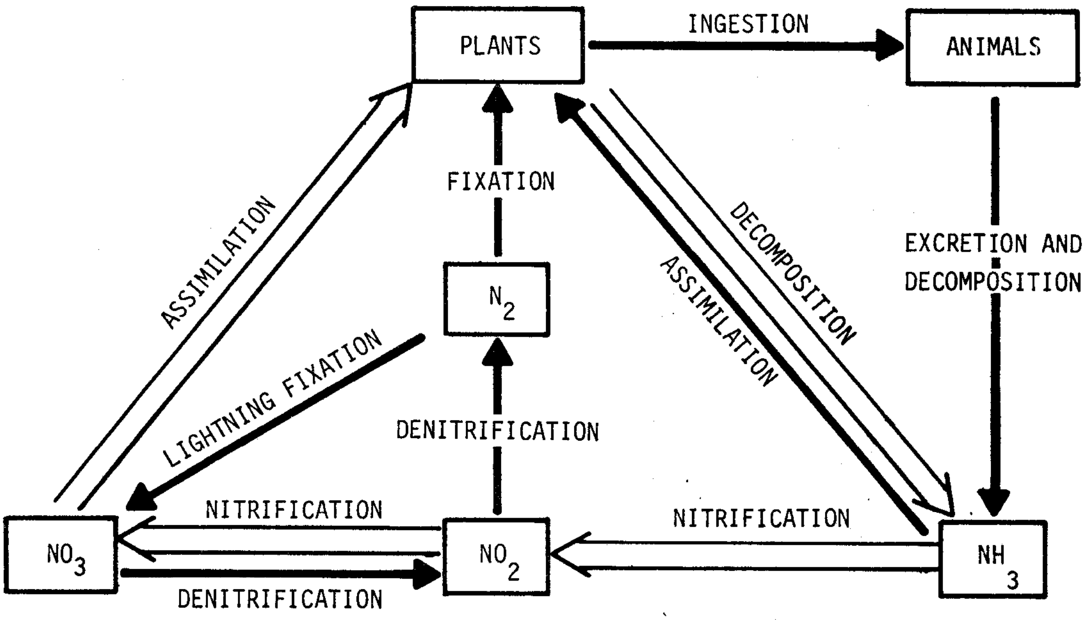


Figure 6. Simplified nitrogen cycle (broad arrows indicate major loop).

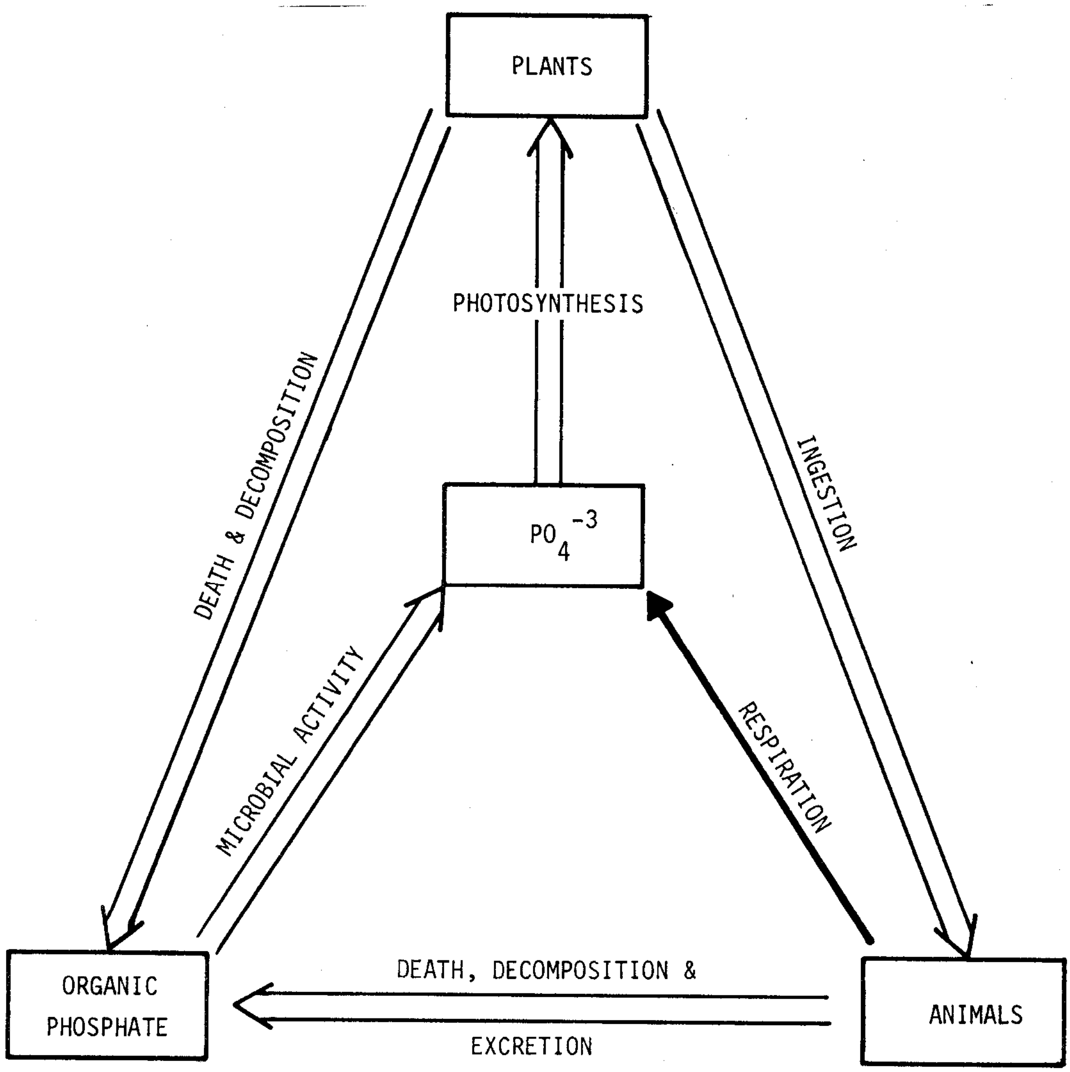


Figure 7. Simplified phosphorous cycle.

Chlorine is not a natural constituent of the biosphere as a gaseous element. In its ionic form, chloride, however, is the most common dissolved constituent of natural waters and a major contributor to salinity, specific conductance and dissolved solids. The principal ecological significance of chloride is in the maintenance of osmotic balance (organisms expend metabolic energy to maintain a solute concentration gradient between the interior and exterior of cells). This physiological role is shared with other major ionic constituents in the aqueous medium (chiefly the cations, sodium, potassium and calcium, which also control reflex responsiveness and neuromuscular functions in animals). Free available chlorine dissolved in an aqueous medium is extremely toxic. Chlorine added to nitrogenous wastes (as a disinfectant) may combine with ammonia to form highly toxic and persistent chloramines.

Trace metallic compounds include many, such as copper and zinc, known to be vital to life in minute quantities. Most metal salts exhibit toxic properties when present in quantities many times the natural or background levels. Mining and manufacturing activities have made some metal salts, which were previously never of any consequence in the biosphere, prevalent hazards. Once in the biosphere, toxic metals do not necessarily behave as a class. Certain metal salts (e.g. zinc) have their centers of distribution in polluted sediments, whereas, others (e.g. chromium) appear to concentrate in certain portions of the biota (chromium in plankton, Phelps, *et al.*, 1973). Hardness, attributable chiefly to calcium and magnesium ions, appears to afford some protection against metallic ion toxicity (McKee and Wolf, 1963).

A few toxic non-metallic inorganic compounds, such as those of boron, beryllium and selenium, do not fit into any of the categories above. Such compounds, like many of the toxic compounds considered, have historically had rather limited distribution in nature, until the advent of man's industrial activities.

B. SYSTEM RESPONSES

There are various ways in which the availability and impact of the abiotic variables considered above can be modified, limited, or enhanced in the biosphere. Some of these processes are abiotic themselves. Others are biochemical and geophysical processes in which living organisms are an important link. In the third set, the responses of the organisms themselves, provide the pathway for change.

1. Physical and Chemical Processes

Overturn is the process by which a freshwater body (i.e. a lake or deep reservoir) recirculates and vertically mixes water layers from various depths. It is accomplished by a combination of winds blowing across the surface and seasonal changes in temperature. The thermal contribution to overturn stems from the fact that pure water is most dense at about 38°F, yet it remains liquid to 32°F. In temperate regions, many lakes overturn twice a year, once during spring, when water temperatures at the surface (near 38°F) become denser than at the bottom (below 38°F), and in autumn, when cooling temperatures also make the surface waters denser than the warmer bottom layers. Overturn is a time of rejuvenation for the aquatic ecosystem -- bottom waters are reaerated and the surface water primary producers receive a renewed supply of nutrients from bottom decomposition. An equivalent process which results from upwelling occurs seasonally in the marine environment. In impounded water bodies with fresh surface waters and brackish or saline bottom waters, overturn is especially difficult because the dissolved solids increase density and make the body of water resistant to mixing. Such water bodies rarely, if ever, overturn. When and if they do (e.g. during an unusually long period of very strong autumn winds) the consequences may be temporarily catastrophic, because of the accumulated products of incomplete decomposition during the years of no overturn.

Stratification is the other side of the coin from overturn. When heat (above 38°F in fresh waters) is introduced at the surface of a standing of slow moving body of water, it makes upper water layers much less dense than lower layers. The impedance to vertical flow thus created is called thermal resistance to mixing. Thermal stratification is not normally an attribute of streams, except where there are dams or barely flowing areas (backwater pools) along the stream course. Stratification can be intensified by discharges of effluent, many of which are substantially warmer than the ambient water. In addition to providing a warm "plume" at the surface, the heated effluent may impede reaeration of the water layers below. In a stream, heated effluents should enter where there is sufficient turbulent flow to overcome thermal resistance to mixing.

In a terrestrial environment, leaching begins with water (usually from precipitation or irrigation) penetrating into the soil. Soluble soil constituents which are in excess of the amount that can be bound to root hairs or soil particles are carried downward with gravity. In a mature ecosystem, leaching is held to a minimum by metabolic activity in the roots. A concentration gradient is maintained such that fluids in the plant contain more solutes than the soil moisture. Changes in soil chemistry (e.g. pH or the relative amounts of physiologically active ions such as calcium, potassium, sodium and chloride) can materially affect the ability of the soil-plant system to retain and absorb such scarce ions as nitrate and phosphate. In dry porous soil, the leachate may percolate past the soil horizon and enter the ground water. In wet or poorly drained soil the leachate may leave the system as runoff.

Stream flow is a major means of export of materials from both terrestrial and freshwater ecosystems. Marine ecosystems are the ultimate importers. Communities within a free flowing stream are unique in that they must cope with a completely open ended energy and nutrient flow. There is little possibility of recycling within the stream itself. Flow rate is an important criterion because it provides the stream with the capacity to assimilate and dilute transported substances. Under natural conditions the volume of stream flow reflects trends in the surplus of precipitation over evaporation. Streams typical of the New England Region are usually swollen in the spring from melting ice and snow, plus heavy rainfall. By August, however, the surplus of precipitation over evaporation has been eliminated by warm temperatures and strong sunlight; streams usually shrink to their lowest levels at this time. Summer is often the time of greatest biological activity in a freely flowing stream, not only because of the warm temperatures but also because nutrient substances are concentrated by the low volume. By the same token, this is the period of greatest single potential impact on the river ecosystem by human activities.

Chemical complexation accounts for the strong correlation between the accumulation of organic materials in sediments and the concentration of many toxic metallic salts. A number of metal ions form chelated (Greek chela, claw) complexes with organic chemical groups (e.g. amine groups, NH_2 and organic sulfides).

2. Biochemical Processes

Biogeochemical cycling is the process by which the chemical constituents of life circulate as elements or in various compounds between organisms and their environment. The overall cycle can be separated conceptually into its various subunits, also called cycles. The much simplified cycles shown in Figures 3, 6, and 7 indicate the circulation of carbon, nitrogen, and phosphorous. Each cycle indicates the chemical processes of living organisms (formation, alteration and decomposition of organic compounds) and the chemical processes of the inanimate portion of the biosphere (formation and transport of inorganic compounds). Ecological imbalances resulting from excess accumulation of certain materials, such as carbon and nitrogen or shortages of such materials as oxygen, can cause the collapse of normal cyclical relationships and consequently, of the ecosystem itself.

Regulated and non-regulated accumulation of substances by living organisms is greatly affected by the external environment. For example, potassium ions are actively imported across cell membrances in contact with the external environment, whereas sodium ions are exported (to maintain cell excitability). Living organisms (except for certain primitive marine forms) contain more potassium in their body fluids and less sodium than in the external medium. Uptake of some ions in the process of active transport may be inadvertant, as when strontium ions (which have very similar chemical properties) accompany the incorporation of calcium ions. A great many ionic and other easily soluble substances which are found to be concentrated in living organisms may have been introduced via active transport across cell membranes. Other substances can be acquired by the animal consumer chain along with the ingested food. However substances which accumulate are acquired, they continue to build up to higher and higher concentrations unless they can be exported or excreted. Concentrations of substances which are difficult to export tend to be further magnified at each trophic level. Certain compounds of lead, mercury and the chlorinated hydrocarbons are notorious examples of noxious substances which magnify until toxic levels are reached. Consequently, the upper trophic levels (the top carnivores, which include man in some circumstances) usually suffer the most damage from the introduction of substances which biomagnify.

3. Ecological Responses

The relationship of an organism to its abiotic environment is represented in Figure 8. Shelford's Law views the success or failure of an organism as controlled by the deficiencies and/or excesses of critical environmental variables (e.g. temperature, heavy metal salts). Although this concept does not take into consideration the interaction between variables, it does provide a springboard for discussion of the possibilities of interaction. As an example of this type of interaction, it has been shown with the lobster, *Homarus americanus,* that a shift away from the optimum range for temperature reduces or narrows tolerance limits for both dissolved oxygen and salinity (McLeese, 1956). Presumably this holds true for many other variables and other organisms, but it has not been proven to fit all cases. The relationship between hardness and heavy metal toxicity is a case in point. The concept of an optimum hardness would be an interesting one to explore.

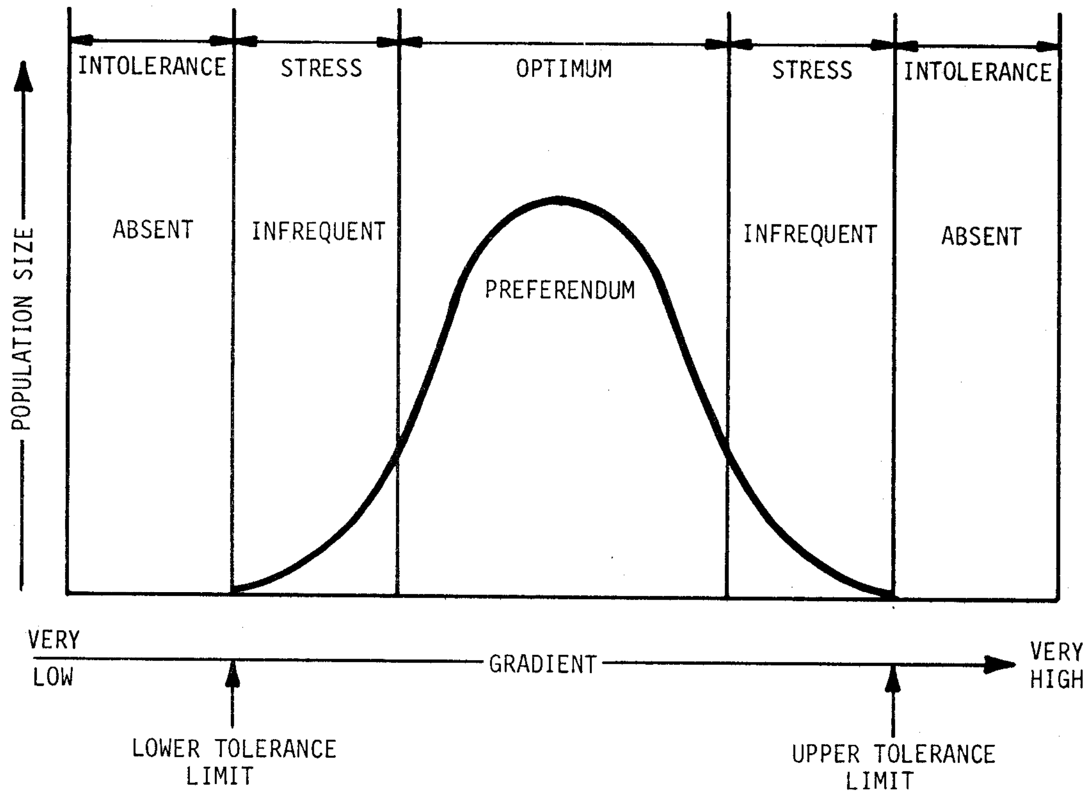


Figure 8. Illustration of the concepts in Shelfords Law of Tolerance.

The organism, however, is an active participant in the ecosystem; it does not merely accept changes in the abiotic environment, it attempts to adapt to them. An organism has several possible options for adaptation. If the change is within tolerance limits, physiological adjustment usually begins immediately and may result in a shift in tolerance range in a matter of days or weeks (under controlled laboratory conditions the term acclimation is used to express this shift). Behavioral responses (typically escape reactions) may also be initiated at once. In addition, organisms have the capacity to resist short lived changes in abiotic factors, even those which surpass incipient tolerance limits. Thus, for example, lethal consequences of a three or four hour depression of dissolved oxygen levels to near zero in a pond during the night may be resisted by some kinds of aquatic organisms although they could not possibly survive under such conditions for very long.

If a change in an abiotic variable occurs over a relatively long period of time, approaching the life span or generation time of an organism, the organism may respond with phenotypic adjustments. These are adjustments which depend on conditioning in parent organisms or in early developmental (immature) stages (e.g. stunted growth when faced with chronic nutrient shortages). If the change is extremely long lived relative to generation time, options for genetic adaptation may be open to the species population.

It is useful to categorize organisms according to whether they have relatively broad (eurytopic) or narrow (stenotopic) tolerance ranges to a variety of abiotic factors. This categorization can also be made in terms of specific factors (e.g. stenothermal, euryhaline). The eurytopic organism is a generalist; its response to changing abiotic factors is typically physiological. Ubiquitous (cosmopolitan) forms found in relatively harsh environments tend to have these characteristics. Competition of eurytopic organisms with organisms well adapted to a specific environment rarely favors the eurytopic species; population densities of eurytopic organisms tend to be maximized under less than optimum abiotic conditions. The stenotopic organism, on the other hand, is a tough competitor given optimum abiotic conditions; its response to changing abiotic variables is typically genetic; gradual changes over very long periods of time (relative to generation time) favor this type of organism, whereas rapid changes may preclude its survival. Distribution of stenotopic organisms tends to be local or restricted to specific types of ideal environments. While these designations are primarily conceptual, there are organisms in the biosphere which fit into one or the other category very well.

Population responses are typically expressed in rates of changes in numbers. For example, a surplus of birth over death rates results in population growth. Environmental resistance (tolerance limits, intra and inter specific competition) imposes restraint on growth so that it is ultimately logistic (S-shaped) rather than exponential (J-shaped), as it may appear to be under initial or pioneer conditions. Population equilibrium is reached when the number of individuals is no longer changing appreciably. The concept of niche (i.e. living space) is useful in considering competition for resources or space. When intra specific competition exerts a restraint on growth which is greater than or equal to the restraint exerted by inter specific competition, niches of the species involved are said to be separated. By definition there can be no equilibrium while the niche occupied by one species overlaps that of another. One of the species must be removed from the overlap before dynamic equilibrium is reestablished. The outcome may hinge on inherent superior qualities of one of the competing species (qualities better suited to the particular niche) or simply numerical superiority (the species "first with the most"). Some populations appear to maintain competitive vigor only when they are in the exponential growth stage. Once the carrying capacity of the environment is reached and the growth rate levels off, the colony comes under stress and become vulnerable to competition from species which are now relatively more vigorous. These events are most typical of very small bodied organisms with very short generation times. (e.g. bacteria, phytoplankton).

Ecological communities have one characteristic in common, that of dominance. The dominant species or groups receive the full impact of the environment (a role for which they are best suited) and alter it to suit their needs, thereby providing niches for associate or subordinate species. On land and in well lighted waters the dominant organisms are specific plants. In dimly lit waters, the dominants are animals. In early stages of ecological succession the dominants tend to be eurytopic species; the barren ground pioneer stage "lichens" are good examples. Lichens alter the substrate, making conditions optimal for more stenotopic, but fiercely competitive, species. Sere replaces sere, as conditions reflect the optima for a succession of increasingly stenotopic forms. As successional development approaches maturity, niches become more finely divided and competitive interaction becomes less fierce until the community is so tightly interwoven that it completely resists further invasion. At this point the ecosystem may be essentially biologically controlled, as are many tropical ecosystems. Biological control means that catastrophic events (fire, floods, epidemic diseases, pest plagues, etc) have minimal impact. The system is self regulating so that the effect of such occurrences are dampened (fire resistant growth, natural predator and parasite control of pests, etc.). Biological control exists to some degree in mature temperate communities, but the necessity of dealing with seasonal fluctuations means that a considerable degree of physical control is retained. Species diversity is a useful index of the relative degree of physical and biological control. Communities with the highest species diversity (number of varieties) usually have the greatest biological control. Near monocultures, such as are represented by agricultural crops, are notoriously lacking in biological control; plant diseases, parasites, and other pests are constant threats.

Biological control is only marginally possible in the aquatic environment. Life in a pond or stream is so dominated by fluctuations in physical parameters that community development is essentially arrested. Emphasis is on high rate of increase and short generation times. Primary producers are small bodied (single celled plants) with large surface to volume ratios. All of this is comparable to the early stages of successional development on land. In a physically controlled environment, successional development towards stability and biological control tends to progress further if the fluctuations on physical parameters are predictable. For example, if a lake overturns regularly once or twice a year, its fauna and flora are usually more diverse than a lake which seldom overturns. Environments subject to waste effluents are usually good examples of unpredictable environments (especially where discharges are discontinuous or discharge quality fluctuates). Unpredictably stressed environments select for eurytrophy, very high rates of natural increase and lack of niche specialization. In the unpredictable environment competitive interaction is a sporadic event. Populations are usually recovering from, or undergoing renewed physiological stress. When competition does occur, it is usually counterproductive, selecting a victorious species of the moment which, however, has an uncertain future. Short term diversity is very low, but the attractiveness of unexploited resources, made available by the severe stresses which have impaired habitation by the preceeding species, makes a chain or progression of opportunistic species likely. A polluted stream, for example, may have a considerable variety or diversity of living forms over the length of its course and long periods of time; at a single point in space or time, however, the variety of living forms present is usually low. Many of these same principles are strongly illustrated in the Merrimack River watershed.

III. WASTEWATER MANAGEMENT IN RELATION TO AQUATIC AND TERRESTRIAL ECOSYSTEMS

A. AQUATIC ECOSYSTEMS

1. Physiographic and Historical Setting

The Merrimack River Basin (Figure 9) comprises an area of 5010 square miles, 1210 of which are in Massachusetts. The total basin length is 150 miles, and the average width is 50 miles. The Merrimack is the fourth largest river basin in New England and, when considered as an interstate basin, it is second only to the Connecticut.

Originating in the White Mountains of New Hampshire, the Merrimack River proceeds in a southerly direction through central New Hampshire to a point in Tyngsborough, Massachusetts, where it turns abruptly and flows generally northeastward for 45 miles to Newburyport, Massachusetts. Here it empties into the Atlantic Ocean. The total length of the Merrimack River is 110 miles, of which the last 22 are affected by ocean tides.

In the Massachusetts portion of the basin, low rolling hills are the dominant topographic features. The geologic structure of the basin is almost entirely composed of granite and gneiss covered to a varying degree by glacial sand and gravel deposits. Since it is glaciated terrain, large drumlins are common in the Massachusetts section of the basin. In general, the watershed line is quite well defined except in the coastal lowland areas where the boundary is less well defined. Sandy loam soils are generally a characteristic of the Massachusetts section of the basin. Out of a total basin area of 5010 square miles, 3.7% or 183 square miles is water surface area. Somewhat more than half of this area is contained in four headwaters region lakes.

Approximately 20% of the basin area (1000 square miles) was cleared farmland in the early 1950's. For the most part, this cleared land was situated in the New Hampshire bottom lands, but some was scattered in rolling hills in the Massachusetts section of the basin. At present, much of the farmland is being replaced by housing developments. There is little virgin timber remaining in the Merrimack River basin. Most of the woodlands are dominated by mixed hardwoods, however there are some scattered stands of coniferous trees.

The mainstem of the Merrimack River in Massachusetts is lined with important manufacturing cities, this being the oldest and most

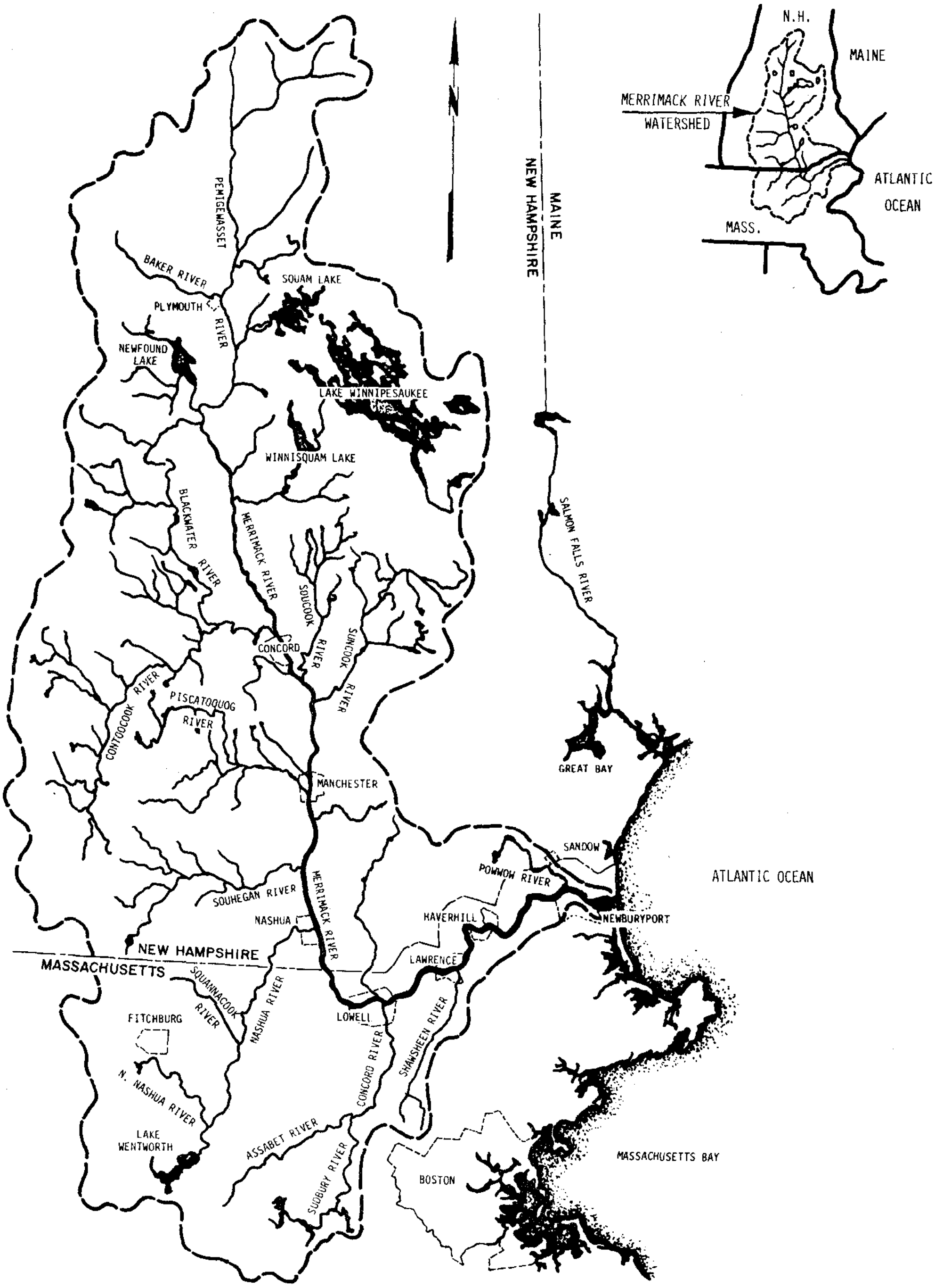


Figure 9. Merrimack River Watershed.

urbanized and industrialized area of New England. The once dominant textile industry has been replaced by more diverse industries, including leather processing, metal plating, paper, and others.

In addition to the major population centers abutting the Merrimack mainstem, many smaller industrial cities are present along its tributary streams. The ten urban centers listed in Table 2 accounted for more than half of the total basin population in 1970.

Principal agricultural activities carried on in the basin are dairy farming, poultry production, and truck farming. The majority of the productive agricultural land is in the southern part of the basin.

The Merrimack River Basin exhibits temporal and spatial climatic variability, with northern areas experiencing greater seasonal variations than southern portions, where the Atlantic Ocean exerts an ameliorating influence. The basin experiences short periods of intense precipitation, although over the course of a year a fairly uniform pattern of precipitation emerges. The average annual precipitation for the entire basin is approximately 42 inches. Mean annual precipitation in the southern portion is somewhat lower than that of the northern portion, but a slightly greater range is evident. Since the basin lies in the path of prevailing westerly winds, summer often brings hot dry weather and concomitant droughts. The coastal portions of the basin are exposed to extreme rainfalls, due both to tropical storms and "northeasters".

The average annual temperature for the basin is approximately 45°F, with a range of 46°F in the south and 43°F in the north. Average seasonal extremes are 73° in July in the southern portions of the basin, to 20°F in January in northern latitudes. Periodic temperature extremes range from highs in excess of 100°F to lows of about -30°F.

During the winter months, precipitation in northern and central sections of the basin occurs primarily as snow, while the southern basin experiences alternate periods of snow and rainfall. Average annual snowfall in the basin has varied from 56 inches at Lowell, Massachusetts to 87 inches at Plymouth, New Hampshire.

a) MERRIMACK RIVER MAIN STEM

Prior to intensive industrialization of the basin shortly after 1800, the Merrimack River supported a variety of fish and invertebrate life. With rapid industrialization and urbanization however, the River was used to an increasing

TABLE 2. MAJOR POPULATION CENTERS IN THE MERRIMACK RIVER BASIN

STATE	COMMUNITY	RIVER	POPULATION (1970)
New Hampshire	Manchester	Merrimack	87,754
	Nashua	Merrimack	55,820
	Concord	Merrimack	30,022
Massachusetts	Lowell	Merrimack	94,239
	Lawrence	Merrimack	66,915
	Haverhill	Merrimack	46,120
	Framingham	Sudbury	64,048
	Fitchburg	Nashua	43,343
	Natick	Sudbury	31.057
	Leominster	Nashua	32,939

extent as a transport medium for industrial and municipal wastes. Compounding this problem was the fact that impoundments were constructed which increased mean residence times of the pollutants, led to siltation of important fish spawning grounds, and restricted dispersion and migration of resident and anadromous fishes. The biologic consequence of such activities was a degradation of aquatic environments both through physical habitat restriction and/or direct or indirect (food chain) pollutant toxicities. Thus, the diversity of aquatic life was greatly decreased and human usage of the waters for consumptive and non-consumptive purposes was limited.

With the closing of many industries along the river after World War II, water quality improved, but other industrialization coupled with population growth counteracted this improvement, and in reality only a shift in contaminant type occurred. Only recently has wastewater treatment, even at the primary level, been instituted by communities along the river. The development of sewage treatment capabilities by certain towns has greatly improved water quality in the river, although it can still be considered strongly polluted from Manchester, New Hampshire to Newburyport, Massachusetts. Above Manchester, the river shows very little pollution at present; indeed water quality within 50 miles of the headwaters region is generally of drinking water quality (Collier, *et al.*, 1972).

b) MERRIMACK RIVER ESTUARY

Where the Merrimack River meets the Atlantic Ocean, a special and distinctive environment prevails. This is the estuary, variously referred to as an "ecotone", or "buffer zone". Because of its physical, chemical, and biological properties, the Merrimack River Estuary, like all estuaries plays an extremely important and unique role in the economy of both man and nature. If one reviews the events, processes, and conditions occurring in various saline environments, the biological significance of estuaries becomes immediately apparent. Estuaries function as important nursery grounds for fish and are considered the most productive of all ecosystems in terms of energy transfer and trophic exchange. Disruption of the physical and chemical conditions that nurture this highly productive ecosystem can have far reaching effects on the biosphere and on man himself.

The Merrimack River Estuary is basically rectangular in shape. It has a maximum length of 6.7 statute miles and a maximum width of 1.8 statute miles at mean high water (Jerome, 1965). The depth of the estuary varies from 11.0 feet at mean high water to 9.6 feet at mean low water. Maxima of 53.0 and 45.0 feet have been recorded at high and low tides, respectively.

The Merrimack River estuary has a total mean high water surface area of approximately 4,000 acres. At mean low tide the surface area is decreased to 53% of its high tide area. In addition, the Merrimack River Estuary undergoes a large volumetric change between high and low tides. Although Jerome, *et al.*, (1965) claimed that this meant faster flushing and greater dilution for the Merrimack River Estuary, salinity data from Hartwell (1970) indicate that freshwater discharged from the Merrimack River is actually impounded during the flood tide. This indicates a reduced exchange of fresh water since the bulk of the water exchanged would be unmixed saline water. Because of this, upstream pollutant discharge would tend to be impounded during flood tide, reducing the dilution capacity of the estuary.

Average depth of the Merrimack River Estuary is about 11 feet (Jerome, *et al.*, 1965) and the estuary supports a substantial amount of shoal area. Jerome, *et al.*, (1965) states that this type of physiography provides a high nutrient availability. Consequently the shallow depths receive a more uniform exchange of nutrients, resulting in a high degree of productivity per unit area when compared to other estuarial systems.

c) TRIBUTARIES

Major tributaries of the Massachusetts portion of the Merrimack River are the Squannacook, Shawsheen, Powwow, Sudbury, Assabet and Concord Rivers. The Squannacook River is a part of the Nashua River drainage, which empties into the Merrimack just above the Massachusetts state line (Figure 9). The drainage basin has a total area of 62.8 square miles and a main stream 13.5 miles in length. Approximately 60 acres of this basin is water surface (exclusive of the Townsend Harbor impoundment).

The Squannacook River is supplied by 44 miles of tributaries which are moderately fast to rapid; are mainly unpolluted; and comprised of well-shaded streams.

The Squannacook River is a well shaded stream with a shifting sand bottom and heavily undercut and eroded banks. For the most part, the river flows smoothly without significant stretches of rapids characteristic of other rivers in western Massachusetts. Logs and toppled trees afford good fish habitat by providing pools and shelter. The Squannacook has a highly variable flow. Spring floods and pronounced summer low flows are the rule. Its pools, however, contain sufficient volumes of water to maintain aquatic life during periods of drought. Records from the U.S.G.S. gauging station at West Groton dating from 1949 often show flows in excess of 1000 cfs with an all time maximum of 4010 cfs on 16 October 1955 and an all time minimum of 2.0 cfs on 7 September 1965. Mean daily flow for all months is 100 cfs.

A dam, 10 to 15 feet high, at Townsend Harbor forms a 51 acre impoundment which is undergoing rapid sedimentation (maximum depth 11 feet). This dam represents an impassable barrier to upstream migration of fish. Above the dam the Squannacook receives a limited amount of municipal sewage through direct input and seepage, but the river there can generally be considered lightly polluted. Below the dam, washwater from a small leatherboard factory creates a moderately polluted condition for about seven river miles.

The Shawsheen River originates in Bedford, Massachusetts (Figure 14, page 66). It proceeds, with a gradient of 7.1 feet/mile, northeasterly for a total distance of 24 miles to its confluence with the Merrimack River at Lawrence, Massachusetts. The Shawsheen drains an area of approximately 73.1 square miles, of which 0.42 square miles are lakes, and 6.12 square miles are swamplands. Total water area in the basin is 118.7 acres. In general the stream is approximately 50 feet wide and two feet deep, with an occasional pool. The river is fairly swift moving with a bottom composed primarily of coarse and medium sand with some riffle areas underlain by rock and cobble. The river is moderately polluted below Bedford but becomes more severely polluted with waste discharges as it passes through Andover, Massachusetts. Aquatic vegetation is abundant, and the stream is somewhat shaded by overhanging trees and shrubs. For most of its course the Shawsheen passes through cleared terrain of low relief with relatively high human population densities.

The Powwow River originates in Sandow, New Hampshire, and flows southeasterly at a gradient of 13.3 feet per mile along an irregular course to Amesbury, Massachusetts where it joins the Merrimack River (Figure 9). The river is approximately 10 miles long (6.7 miles in Massachusetts), and drains approximately 61.4 square miles.

The Powwow is impounded above Amesbury to form Lake Gardner. It drains an area in Massachusetts (exclusive of Lake Gardner) of approximately 20.3 acres. Mid-way along the stream the Powwow is approximately 40 feet wide and approximately 2 feet deep. The construction of I-495 affected the channelization of the lower reach of the Powwow below Amesbury. The old channel meander forms what is essentially an oxbow, and this is being rapidly silted in.

For the most part, the Powwow flows through cleared terrain of low relief and low population density. The town of Amesbury appears to be the only significant source of pollution. Much of the river basin in the Massachusetts section of the Powwow is swampy. In these sections the river bottom is covered with a fairly thick deposit of poorly degraded plant debris. The Powwow below Lake Gardner is a rather slow, plodding river, and is strongly influenced by tidal effects from the mainstem of the Merrimack River.

The Sudbury, Assabet, and Concord Rivers have been collectively referred to as the SUASCO system. This is the most important tributary system joining the Merrimack River in Massachusetts. The Sudbury and Assabet Rivers merge at Concord, Massachusetts to form the Concord River (Figure 15, page 67). The system comprises a total drainage area of approximately 407 square miles covering a variety of terrains and land use types.

The Sudbury River has a drainage area of 163 square miles. It flows easterly from Westborough to Framingham, then turns northward to Concord where it joins the Assabet River. The Sudbury has a total length of 32 miles, and a gradient of 5.0 feet per mile. After flowing through the highly urbanized manufacturing district of Framingham and Natick, the Sudbury flows through low relief terrain of relatively low population densities. The bulk of the basin is marshy and, because of this, there is an abundance of aquatic vegetation (both emergent and non-emergent). A large portion of the river bed is covered with a thick layer of detrital plant material.

The Assabet River has a drainage area of 177 square miles, with a total water area of 56.4 acres. It originates in Westborough, Massachusetts, flows northward to Hudson, and then turns northeasterly to Concord where it joins the Sudbury River. As it flows along its 31 mile course the Assabet traverses both open swamp and meadowlands. The bottom consists primarily of sand and mud, and the gradient is about 6.5 feet per mile. This medium-sized, poorly-shaded river has a width of approximately 50 feet and a depth of approximately 1 foot. Interspersed along its course are long, ponded areas as well as short riffle sections. Unlike the Sudbury, the Assabet drains a series of small industrial towns rather than a large urban area. Below Westborough, the Assabet is severely polluted. From there on, the river in preparation)] being conducted in Hooksett Pond, Bow, New Hampshire. In addition to monitoring temperature, depth of visibility, dissolved oxygen, nutrients and pH, this survey monitors plankton, periphyton, aquatic macrophytes, benthic invertebrates and fish populations. In some cases this data serves as a control ("moderately clean water") for the Massachusetts sections of the Merrimack River.

The most comprehensive survey of water quality and biological conditions conducted in the Merrimack River Basin is given in "Report on Pollution of the Merrimack River and Certain Tributaries" (Pahren, *et al.*, 1966: Part II Physical and Chemical; and Oldaker, 1966: Part III Biological). This survey contains excellent data on dissolved oxygen, biochemical oxygen demand, time of travel, coliform, density, photosynthetic activity, and sediment characteristics. In addition to this, quantitative data are provided for benthic communities existing in the Merrimack River and Merrimack River Estuary. Plankton data for the Merrimack River at Lawrence, Massachusetts are also presented.

Collier *et al.* (1972) present an excellent data set for sodium, potassium, magnesium, calcium, and nitrate and phosphate concentrations along the entire length of the Merrimack River during the summer of 1972. A daily record of dissolved oxygen, temperature, specific conductance and pH collected at the U.S.G.S. water quality monitoring station at West Newbury, Massachusetts for August 1968 - September 1969 is available in the Merrimack River Water Quality Monitoring Data (Massachusetts Water Resources Commission, Division of Water Pollution Control, 1970).

Good accounts of the resident fish populations, and attempts at restoring anadromous fish to the Merrimack River, have been given by Oatis and Bridges (1969), and Wightman and Newell (1971). Additional water quality data are also given by Oatis and Bridges (1969) as are detailed data on substrate and hydrography of the Massachusetts section of the Merrimack River.

The most comprehensive survey of ecological conditions in the estuary is found in Jerome, *et al.*, (1965). This report provides historical and recent data on fish and shellfish populations in the estuary. Additional data on benthic invertebrates, aquatic macrophytes, water quality, and estuarine physiography are also given. Detailed information on estuarine circulation, suspended sediments, and sedimentary environments was studied by Hartwell (1970), and additional ecological information with emphasis on plankton, benthos, and aquatic macrophytes may be found in Normandeau Associates (1971) estuarine report.

The SUASCO (Sudbury, Assabet, and Concord Rivers) system has received the most attention of all the tributary systems. Two major surveys have been conducted by the Water Quality Management Section, Division of Water Pollution Control, Massachusetts Water

Resources Commission on this system (1965, 1973). Water quality parameters measured were temperature, dissolved oxygen, pH coliform bacteria, chemical oxygen demand, suspended solids, and alkalinity. Sediment samples were taken during the 1965 survey, and these were examined for percent volatile solids, grain size composition, appearance and odor, and biologic content. At this time, water samples were also analyzed for plankton composition.

The Assabet River was surveyed during the summers of 1968 and 1968 (Cooperman and Jobin, 1971). Water quality parameters measured included temperature, dissolved oxygen, biochemical oxygen demand, fecal coliforms, total phosphates, and rate of photosynthesis. The reaeration effect of dams was also measured.

During 1965, 1969, and 1970, surveys of wastewater discharge sites on the Assabet River were made (Cooperman, Zdanowicz, and Jobin, 1971). These surveys catalogued the chemical characteristics of influent and effluent waters at Westboro, Shrewsbury, Marlboro-Westerly, Hudson, and the Concord Reformatory secondary treatment plants. The chemical parameters measured were dissolved oxygen, biochemical oxygen demand, pH, total alkalinity, total phosphates, organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. In addition, various physical and biological parameters were measured such as temperature, turbidity, total solids, loss on ignition, settleable solids, and coliforms. The data are generally complete. Wastewater flow rates and treatment methods also were documented.

Other tributary streams have received less attention, but have generally been monitored at least once by the U.S.G.S. The Massachusetts Division of Fisheries and Game (1953) conducted an extensive survey of the fishery existing in the Merrimack River drainage system in 1953, using rotenone, cresol, electrofishing, and entrapment methods. The streams studied included the Squannacook, Shawsheen, Powwow, Sudbury, Assabet, and Concord Rivers. Data from this survey document the abundance of various resident, stocked and anadromous species present in the system. This constitutes the available information on Merrimack River tributary stream fisheries.

Lyman, Noyes, and Heeley (in press) have reviewed the available data on contamination of fish by chlorinated hydrocarbon pesticide, PCB's and mercury levels in the Merrimack River. PCB and DDE levels in Merrimack River sediments and waters were also reviewed. Finally, a general review of the ecology of the Merrimack River Basin and the effect of various wastewater treatment schemes were presented by the U. S. Army Corps of Engineers (1971) report titled "The Merrimack: Designs for a Clean River". This report (and its various appendices) is of limited data value, but does represent a starting point from which the present studies have evolved.

In summary, it can be said that although several surveys have been conducted on the abiotic and biotic components of the Merrimack River Watershed over recent years (the past decade), no one, comprehensive volume exists which binds these data together. This is especially evident for the biological components of the ecosystem, but temporal discontinuities in water quality data exist too. Due to this patchiness of data, it was decided that the present study effort should, in addition to synthesizing existing data, include limited field studies of the entire watershed at a single point in time.

3. Methods and Materials

A general location map of the 14 stations selected for additional field studies from September through October, 1973, is given in Figure 10. Five stations were located on the main course of the Merrimack River in Massachusetts, one was at the mouth of the estuary and nine were on tributary streams in the Merrimack watershed. Stations were chosen either because they were representative of the various water quality conditions in these rivers, or because of their interest as possible effluent discharge sites. Table 3 gives exact sampling locations on the rivers. Sampling was conducted in September and October, 1973. Plants, plankton, and benthic invertebrates were studied. Other parameters measured were surface and bottom dissolved oxygen, turbidity, temperature, depth, flow rate, depth of visibility, and salinity (where applicable). General substrate composition, amount of littoral area, fish habitat, and aesthetics were also examined. In addition, existing outfalls in the immediate vicinity of the sites were noted, and when possible, a general upstream/downstream tour, within approximately one half mile of the site, was made to explore possible sludge deposition areas.

Base line field work failed to disclose sludge deposits either where previous workers had anticipated them, or at any other locations in the one mile stretches of the rivers examined. Most of the potential sludge deposit locations on the mainstem of the Merrimack River exhibited only fine particulate sand. Physical/chemical studies on these sediments were, however, still deemed necessary to gain an understanding of river ecology. Core sampling was conducted at three sites on the Merrimack River, and at one site on both the Concord and Squannacook Rivers.

The following paragraphs indicate methods and materials utilized in assessing ecological conditions in the Merrimack River watershed:

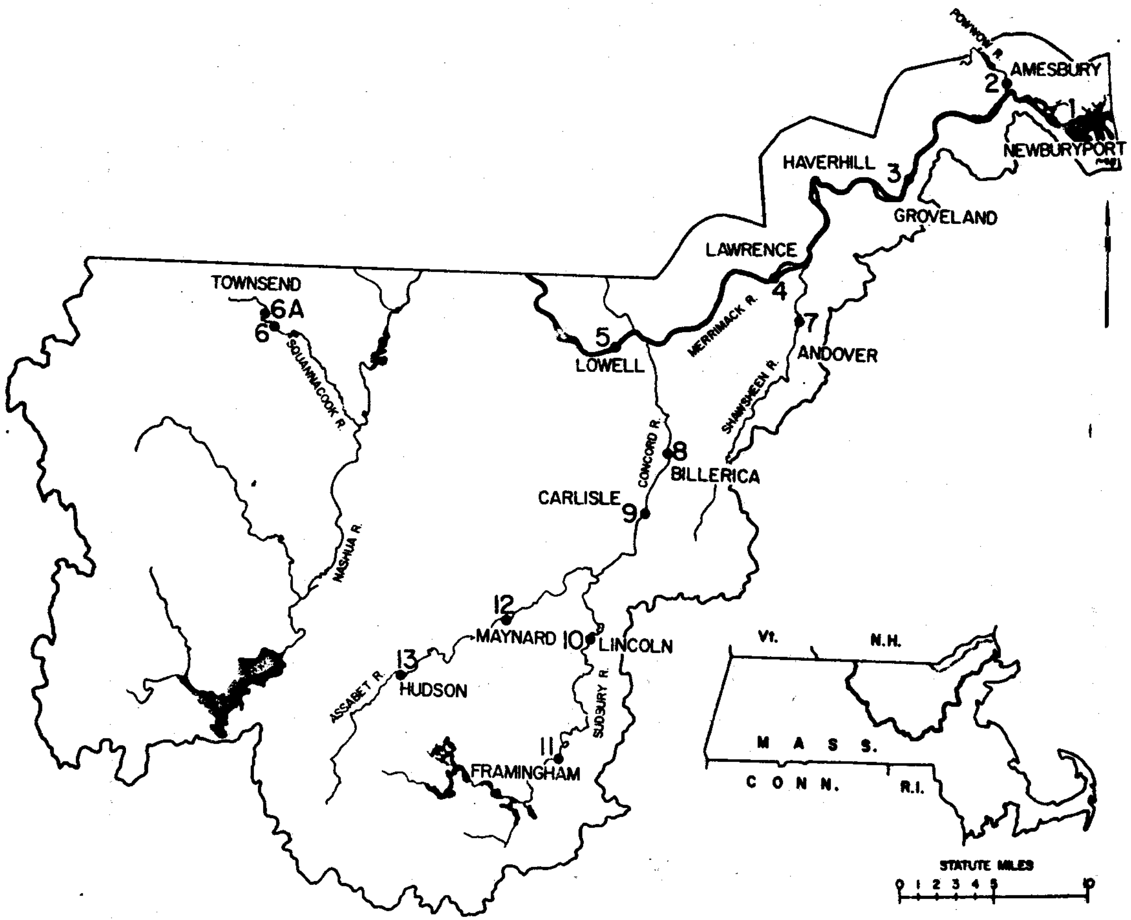


Figure 10. Location of aquatic sampling sites established for field investigations, Fall, 1973.

TABLE 3. LOCATIONS OF SAMPLING STATIONS USED IN FALL, 1973 FIELD STUDIES

STATION	RIVER	DESCRIPTION
1	Merrimack	Newburyport, estuary N-S line ∿through U.S.C.G.S. BM11.
2	Merrimack	Amesbury, upstream of Main Street Bridge above I-495 channelization.
3	Merrimack	Haverhill, downstream from Groveland Street Bridge.
4	Merrimack	Lawrence, slightly upstream of Essex Dam.
5	Merrimack	Lowell, slightly upstream of Pawtucket Dam.
6	Squannacook	Townsend, ∿ .6 miles upstream of Main Street Bridge.
6A	Squannacook	Townsend, slightly upstream of Turnpike Road Bridge.
7	Shawsheen	Andover, downstream of Reservation Road Bridge.
8	Concord	North Billerica, upstream of Pollard Street Bridge.
9	Concord	Carlisle, downstream of Rt.225 Bridge.
10	Sudbury	Concord, upstream of Rt. 117 Bridge.
11	Sudbury	Framingham, upstream of Elm Street Bridge
12	Assabet	West Concord, upstream of Main Street Bridge
13	Assabet	Stow, upstream of Rt. 62 Bridge.

a) PHYSICAL PARAMETERS

1) FLOW AND DISCHARGE

At each sampling station, flow-rate determinations were made using a General Oceanics direct read-out current meter. Detailed information on river discharge was extracted from U.S.G.S. water resources data for the period 1965 through 1971.

2) DEPTH

Cross-sectional depth profiles were made at five, equally spaced intervals across the channel of the river. Detailed bathymetric data were obtained on the Merrimack River from Oatis and Bridges (1969).

3) DEPTH OF VISIBILITY AND TURBIDITY

A Secchi disc was used for depth of visibility determinations at mid-channel, and water samples were returned to the laboratory for turbidity determination, using a Hach model 2100A Turbidimeter. Additional turbidity information was extracted from U.S.G.S. Water Resources Data for 1965-1971.

4) WATER TEMPERATURE

At each station, a YSI field thermistor system was used to obtain a mid-channel temperature profile. Additional temperature information was available from a variety of State and Federal Sources.

5) SALINITY

In the Merrimack River Estuary, and in areas of tidal influence, salinity and conductivity profiles were measured, using a Beckman RS5-3 induction salinometer. Additional salinity data were abstracted from Jerome *et al.* (1965) and Normandeau Associates (1971).

6) SEDIMENTS

At each site, two replicate core samples were taken at each of five stations, which were arranged, where possible, equidistant from one another, along a transect from one river bank to the other. The character of the sediment was also determined by probing with a small diameter steel rod, and by observing material retained in Ponar grab samples. In an attempt to locate "sludge" deposits, sediment reconnaissance was conducted both upstream and downstream of each sampling site, for a distance of approximately 1/2 statute mile.

Locations considered likely sites of sediment contaminated by human activities (Lowell, Lawrence and Haverhill on the main stem, and the Billerica site on the Concord River) were sampled by SCUBA divers, using hand core samplers. Additional core samples were taken at Station 6, on the Squannacook, to serve as a control. Observations of river bed morphology and surficial sediment characteristics were made by the divers during the sampling. The sediment cores were returned to shore where they were photographed and noted for microstratigraphy. Special attention was paid to the surficial detrital layer and the depth to which fresh detrital material was entrained in the underlying substrate.

b) CHEMICAL PARAMETERS

1) DISSOLVED OXYGEN

Dissolved oxygen values were determined by the sodium azide Winkler technique. Water samples were taken from surface and bottom water where possible, using a Kemmerer water sampler. The sample was then fixed in the field and returned to the laboratory for titrations. Additional dissolved oxygen data were extracted from various State and Federal sources.

2) OTHER PARAMETERS

Data on all other abiotic parameters, such as B.O.D., C.O.D., total N, NH_3, total P, PO_4 and metals, were obtained from past reports of various state and Federal agencies.

3) CHEMICAL COMPOSITION OF SEDIMENTS

Sediment core samples collected by SCUBA techniques were returned to the laboratory, where they were frozen and extruded. The top 15 cm. of the extruded cores were retained in a frozen condition until they could be shipped for analysis.

One set of samples was sent to the Center for Industrial and Institutional Development at the University of New Hampshire, where grain-size distribution by hydrometer analysis, fixed and volatile residue, and B.O.D.$_5$ were determined. A replicate set was forwarded to the United States Army Corps of Engineers laboratory at Barre Falls, Massachusetts, where analyses of organic N, total P, zinc, mercury, lead, chromium, cadmium, copper, nickel, and boron were performed.

c) BIOLOGICAL PARAMETERS

1) PLANKTON

Two replicate plankton tows were made at each station, using a #20 mesh net. These samples were fixed in the field with buffered formalin and returned to the laboratory for identification of major groups and dominant organisms within each group. Additional plankton data were abstracted from Oldaker (1966) and various State sources (Commonwealth of Massachusetts, Water Resources Commission, 1971, 1973).

2) AQUATIC MACROPHYTES

A survey of the aquatic macrophyte population was made in the area of designated sampling stations. Species present, and their relative abundance, were noted. Species "type" samples were collected in labeled containers and refrigerated until laboratory identification could verify field observations.

3) BENTHIC INVERTEBRATES

River benthos were collected from three stations at each site, one adjacent to each bank and one at mid-channel. Two replicate $0.05m^2$ Ponar grab casts were taken at each of these three stations. Each cast was then seived, stained, and fixed in the field, using a Rose Bengal buffered formalin solution. These samples were returned to the laboratory where the organisms were separated from the retained substrate, and preserved in 70% alcohol for later identification. Additional information on benthic invertebrates was obtained from Oldaker (1966), Normandeau Associates, Inc. (1971), and a report by the Commonwealth of Massachusetts, Water Resources Commission (1971).

4) FINFISH

Detailed information on fish populations was extracted from Oatis and Bridges (1969), Massachusetts Division of Fisheries and Game (1953) and New Hampshire Department of Fish and Game (1971).

5) OTHER OBSERVATIONS

During the survey, general notes were also made on amount of overhanging vegetation, extent of littoral area, quality of fish habitat, local outfalls and general aesthetics.

Data collected in the field, in tandem with information from the literature, are discussed in detail in sections to follow. A summary of aquatic sampling station descriptions, in the form of field notes, is presented in Appendix A.

4. Water Quality

a) .PHYSICAL

1) DISCHARGE

Table 4 presents mean monthly discharge rates for the Merrimack River at Lowell, Massachusetts, calculated over

TABLE 4. HISTORIC DISCHARGE DATA FOR THE MERRIMACK RIVER BELOW THE CONCORD RIVER AT LOWELL, MASSACHUSETTS, 1935 - 1971

(U.S.G.S. Water Resources Data, 1971)

MONTH	MEAN CFS	MAX CFS	MIN CFS
January	6,315	12,741	1,612
February	6,475	17,900	2,064
March	11,772	44,250	3,953
April	19,012	33,867	8,646
May	11,302	24,370	4,068
June	5,716	11,501	1,784
July	3,043	8,060	1,151
August	2,462	7,330	883
September	3,070	18,877	873
October	3,312	9,211	1,036
November	5,840	17,331	1,824
December	6,619	14,468	2,073
ANNUAL	7,080	10,387	2,985

a 48-year data base. Probabilities associated with annual 7-day low flows calculated from the period of record are given in Table 5. The highest recorded flow in the Merrimack was 44,250 cfs, and the lowest was 873 cfs. A 7-day, 10-year flow of 914 cfs was calculated for the river at Lowell. Seven day, 10-year low flows for five Merrimack tributaries are shown in Table 6. Comparable data on the Sudbury River are not available, however the flow is probably quite similar to the Assabet. At Framingham, the Sudbury is impounded by a large reservoir system; mean daily discharge of the river at Framingham is 112 cfs.

While low-flow periods on the tributaries of the Merrimack River are of comparable duration and magnitude, wide variability exists with respect to maximum flows. Maximum flows for the Squannacook, Assabet, and Concord Rivers are often in excess of 1,000 cfs with peak discharges of about 4,000 cfs. In the Shawsheen, maximum flows rarely exceed 300 cfs with an all-time high of 1,050 cfs being recorded in March, 1968. Minimum flows are given in Table 6 for five Merrimack tributaries.

2) TEMPERATURE

Temperature conditions are similar throughout the lower main stem of the Merrimack River. Temperature records (U.S.G.S., 1966-73) show a range of 32°F to 89°F. January and February are the coldest months (32° to 40°F); July and August are the warmest (63-89°F). Water temperatures rise most rapidly from March to May and decline most rapidly during October and November. On the basis of summer temperatures, the Merrimack River in Massachusetts can be characterized as capable of supporting a warm water fishery.

Temperatures at the mouth of the Merrimack, in the estuary, exhibit less seasonal variability due to the influence of the Atlantic Ocean. Jerome *et al.* (1965) showed that the ocean water was warmer than the Merrimack River water until April, when river waters became warmer. Temperatures in the estuary range from 32°F to 75°F. Tributaries of the Merrimack are cool in their upper reaches (mid to high 60's), during summer but lower stretches of the Squannacook, Shawsheen, Assabet, and Concord Rivers attain temperatures in the mid to high 70's (U.S.G.S. Water Resources data, 1964 - 71).

TABLE 5. ANNUAL 7-DAY LOW FLOW PROBABILITIES
MERRIMACK RIVER BELOW CONCORD RIVER AT LOWELL, MASSACHUSETTS

(U.S. Army Corps of Engineers, 1973)

FLOW (CFS)	% CHANCE
3,800	99.9
2,400	90.0
1,900	80.0
1,800	70.0
1,700	60.0
1,500	50.0
1,400	40.0
1,200	30.0
1,000	20.0
850	10.0
550	1.0
400	∿0.0

TABLE 6. MINIMUM AND 7-DAY, 10-YEAR LOW FLOWS

(U.S.G.S. Water Resources Data 1971, and
U.S.G.S. Personal Communication, 1974)

TRIBUTARY	MINIMUM FLOWS OF RECORD (CFS)	7-DAY, 10 YEAR LOW FLOWS (CFS)
Assabet	0.2	3.2
Concord	4.0	28.4
Powwow	---	4.9
Shawsheen	1.2	5.7
Squannacook	2.0	4.9

3) TURBIDITY

Turbidity in the Merrimack River is not as high as one might expect, although effects of industrial and municipal discharges (especially around Haverhill) cause locally significant turbidity increases. Observations made in late September and early October, 1973, on turbidity and depth of visibility are given in Table 7.

TABLE 7. TURBIDITIES AND DEPTHS OF VISIBILITY MEASURES ON THE MERRIMACK RIVER, OCTOBER, 1973

STATION	TURBIDITY	DEPTH OF VISIBILITY
Lowell	1.8 J.T.U.*	5.0 ft.
Lawrence	2.4 J.T.U.	4.0 ft.
Haverhill-Groveland	4.8 J.T.U.	3.5 ft.
Merrimack Estuary	1.6 J.T.U.	8.0 ft.

*Jackson Turbidity Units

Generally, turbidities on the Merrimack River were about 2.0 J.T.U., with a significant increase in the Haverhill-Groveland area. Depths of visibility ranged from 3.5 to 8.0 feet.

Jerome, *et al.* (1965), in a more intensive study, recorded depths of visibility up to 20 feet, and noted that visibility increased proceeding down river. They also found that visibility in the estuary was generally greatest from May through September. Mean transparency near the mouth of the estuary was 14 feet, whereas mean inshore transparency was 6 feet, (Jerome *et al.*,1964). indicating that suspended materials are deposited within the estuary. This conclusion is supported by Normandeau Associates (1971) and Hartwell (1970) and has important consequences to the biologic community.

Turbidity values observed in the Merrimack River tributary streams, surveyed during September and October 1973, are presented in Table 8. The more rapidly running streams (Squannacook, Shawsheen, and Assabet) had turbidity values ranging from 0.8 to 1.0 J.T.U., while the slower streams (Powwow, Sudbury, Concord) were two to

TABLE 8. TURBIDITY VALUES OBSERVED IN MERRIMACK RIVER TRIBUTARIES SEPTEMBER-OCTOBER, 1973

RIVER	TURBIDITY (J.T.U.)
Squannacook	0.8-1.0
Shawsheen	0.9
Powwow	2.0
Assabet	0.9-1.0
Sudbury	2.0-6.4
Concord	2.8-3.2

six times as turbid.

Depths of visibility in these rivers reached the bottom (3 to 5 feet). Fall, 1973, observations on the Concord River agreed well with observations made by the U.S.G.S. in 1971. Values recorded by Normandeau Associates on the Shawsheen and Assabet Rivers were lower than those reported in the literature [1-4 J.T.U., Shawsheen, (Cooperman *et al.*, 1971); 3.0 J.T.U., Assabet all seasons (U.S.G.S., 1970-71].

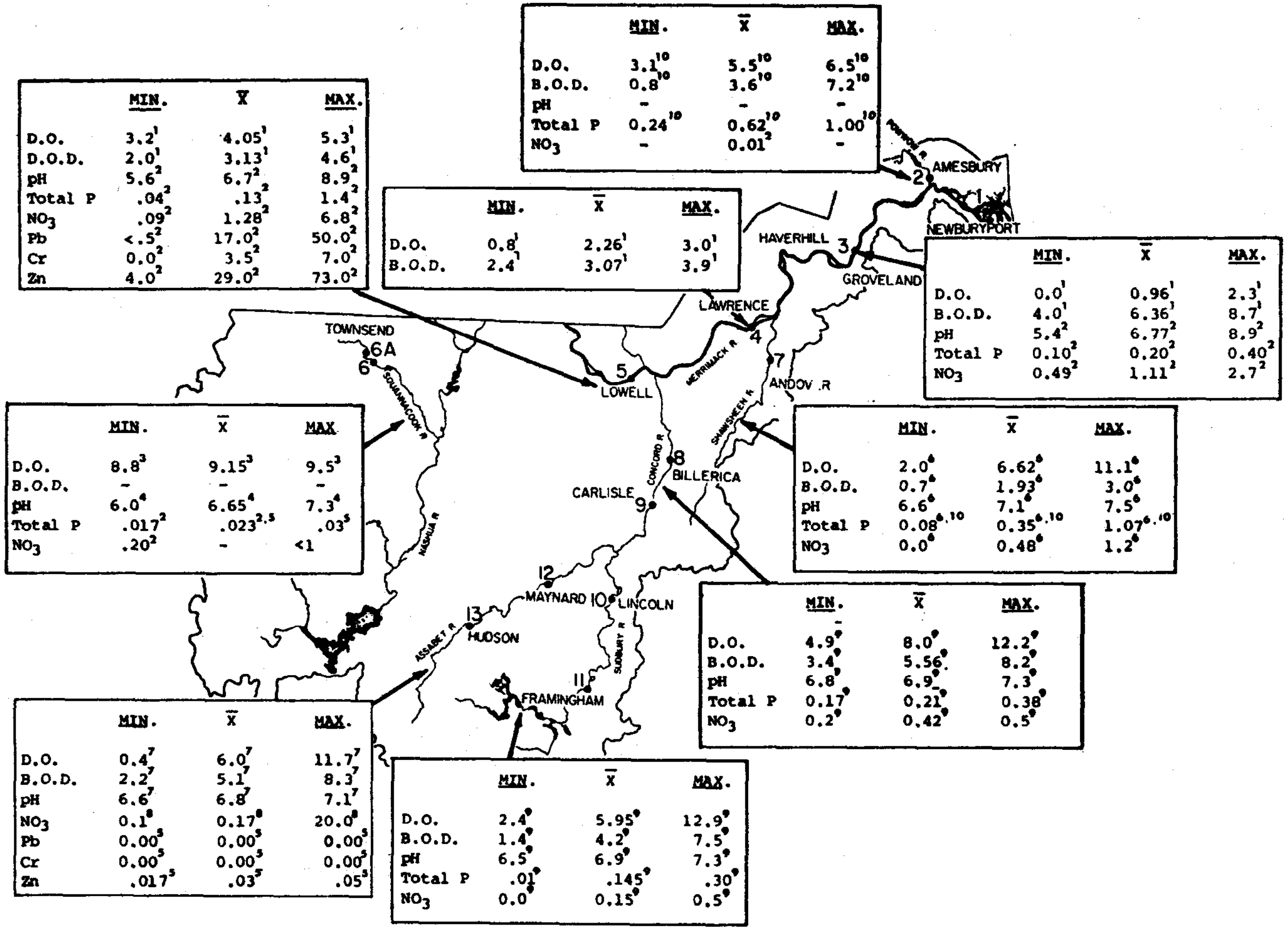
4) COLOR

Color measurements are less available, and biologically less important than turbidity data. Color is measured in what are called Klett units. It can reflect a variety of dissolved and suspended substances, but in shallow stream systems has little singular effect on plants and animals. U.S.G.S. data (1966-1973) on water color in the Merrimack River range from 10-28 units, with a mean of about 17 units. This indicates that the Merrimack River is a moderately "colored" body of water. The only other river for which color data are available is the Shawsheen. Measurements there were from 15-85 units (mean of 53 units) above river mile 10.6.

b) CHEMICAL

Studies of chemical water quality in the Merrimack watershed have predominantly favored such parameters as dissolved oxygen, B.O.D. and pH, with some interest in nutrients, such as nitrogen and phosphorous. Data pertaining to other parameters are scarce; different parameters have been measured at different times and places, and by various chemical techniques. In general, no common ground exists for making rigid comparisons among rivers. This is especially true of the tributary system, but is true even on the Merrimack mainstem. Therefore some liberties had to be taken in compiling, arranging and averaging temporally discontinuous data. Some of this data has been compiled at the beginning of this section (Figure 11 and Table 9) in order to provide a brief overview of water quality in the Massachusetts section of the Merrimack River basin.

Where there are sufficient data to permit comparison between portions of the mainstem and the tributary streams, values have been included in Figure 11. Table 9 presents



	MIN.	$\bar{X}$	MAX.
D.O.	3.2[1]	4.05[1]	5.3[1]
D.O.D.	2.0[1]	3.13[1]	4.6[1]
pH	5.6[2]	6.7[2]	8.9[2]
Total P	.04[2]	.13[2]	1.4[2]
NO_3	.09[2]	1.28[2]	6.8[2]
Pb	<.5[2]	17.0[2]	50.0[2]
Cr	0.0[2]	3.5[2]	7.0[2]
Zn	4.0[2]	29.0[2]	73.0[2]

	MIN.	$\bar{X}$	MAX.
D.O.	3.1[10]	5.5[10]	6.5[10]
B.O.D.	0.8[10]	3.6[10]	7.2[10]
pH	-	-	-
Total P	0.24[10]	0.62[10]	1.00[10]
NO_3	-	0.01[2]	-

	MIN.	$\bar{X}$	MAX.
D.O.	0.8[1]	2.26[1]	3.0[1]
B.O.D.	2.4[1]	3.07[1]	3.9[1]

	MIN.	$\bar{X}$	MAX.
D.O.	0.0[1]	0.96[1]	2.3[1]
B.O.D.	4.0[1]	6.36[1]	8.7[1]
pH	5.4[2]	6.77[2]	8.9[2]
Total P	0.10[2]	0.20[2]	0.40[2]
NO_3	0.49[2]	1.11[2]	2.7[2]

	MIN.	$\bar{X}$	MAX.
D.O.	8.8[3]	9.15[3]	9.5[3]
B.O.D.	-	-	-
pH	6.0[4]	6.65[4]	7.3[4]
Total P	.017[2]	.023[2,5]	.03[5]
NO_3	.20[2]	-	<1

	MIN.	$\bar{X}$	MAX.
D.O.	2.0[6]	6.62[6]	11.1[6]
B.O.D.	0.7[6]	1.93[6]	3.0[6]
pH	6.6[6]	7.1[6]	7.5[6]
Total P	0.08[6,10]	0.35[6,10]	1.07[6,10]
NO_3	0.0[6]	0.48[6]	1.2[6]

	MIN.	$\bar{X}$	MAX.
D.O.	4.9[9]	8.0[9]	12.2[9]
B.O.D.	3.4[9]	5.56[9]	8.2[9]
pH	6.8[9]	6.9[9]	7.3[9]
Total P	0.17[9]	0.21[9]	0.38[9]
NO_3	0.2[9]	0.42[9]	0.5[9]

	MIN.	$\bar{X}$	MAX.
D.O.	0.4[7]	6.0[7]	11.7[7]
B.O.D.	2.2[7]	5.1[7]	8.3[7]
pH	6.6[7]	6.8[7]	7.1[7]
NO_3	0.1[8]	0.17[8]	20.0[8]
Pb	0.00[5]	0.00[5]	0.00[5]
Cr	0.00[5]	0.00[5]	0.00[5]
Zn	.017[5]	.03[5]	.05[5]

	MIN.	$\bar{X}$	MAX.
D.O.	2.4[9]	5.95[9]	12.9[9]
B.O.D.	1.4[9]	4.2[9]	7.5[9]
pH	6.5[9]	6.9[9]	7.3[9]
Total P	.01[9]	.145[9]	.30[9]
NO_3	0.0[9]	0.15[9]	0.5[9]

Figure 11. Summary of selected water quality parameters, Merrimack River Watershed (see footnotes on following page).

FOOTNOTES

[1]Pahren, *et*. *al*. (1966) August 1964 data.

[2]U.S.G.S. Water Resources Data 1966-1973.

[3]NAI Data September-October 1973.

[4]Mass. Div. Fisheries and Game, 1953.

[5]U.S.A.C.E. Data August-December, 1973.

[6]Cooperman, Costello, and Jobin, 1971 (August 1968 data).

[7]Cooperman and Jobin, 1971 (August 1969 data).

[8]Mass. Water Resources Comm., 1973 (July 1965 data).

[9]Mass. Water Resources Comm., 1973 (August 1973 data).

[10]Pahren, 1966 (July 1966 data).

Data presented in this figure are in ppm, except for Pb, Cr, and Zn which are in ppb.

TABLE 9. SUMMARY OF WATER QUALITY DATA, MERRIMACK RIVER

(Values averaged over a one-year period)

	ABOVE LOWELL		BELOW CONCORD RIVER AT LOWELL					WEST NEWBURYPORT
	1972	1973	1966	1968	1969	1970	1971	1973
SiO_2	--	5.3	5.0	4.7	5.0	3.8	4.96	--
Fe	.320	.550	.233	.248	.254	.050	.256	.260
Mn	60	72	52.5	108	45.7	20	100	40
Ca	7.0	4.6	7.1	6.3	6.4	6.2	6.7	6.3
Mg	1.1	.76	1.2	1.1	1.3	1.1	1.1	1.1
Na	12	11.1	10.8	10.1	11.2	11.4	13.3	10.7
K	1.5	.8	--	1.35	1.15	1.12	1.33	1.2
NH_3	1.8	.37	--	--	--	--	.71	.47
HCO_3	25	7.6	10.6	9.0	8.5	2.9	15	11
SO_4	12	8.6	10.5	13.6	13.4	12	12.6	10.2
Cl^-	17.0	10	13.8	15.7	17.3	15.5	18.3	16.3
F^-	.3	.4	.27	.17	.13	.125	.03	.3

Continued

TABLE 9. (Continued)

	ABOVE LOWELL 1972	1973	BELOW CONCORD RIVER AT LOWELL 1966	1968	1969	1970	1971	WEST NEWBURYPORT 1973
CO_3	0	0	0	0	1.14	--	--	0
NO_2	.026	.02	--	--	--	.11	.015	.06
NO_3	.44	1.1	2.5	2.5	3.35	3.65	.76	2.5
Total P	.10	.07	.96	0.5	.575	.29	.248	1.2
Dis. Solids	72	53	74	78	67	72	78	--
Ca Hardness Mg	22	14.8	14	20	20	21	22	20
Non-Carbonate Hardness	2	8.4	--	9.8	12.3	8.5	9.3	11
Conductance MV/CM	101	58	108.5	103	117.6	104.5	124	103
Color (units)	25	--	17	18	28	10	14	10
pH (units)	6.8	6.7	6.17	6.06	6.5	6.88	6.71	--
Loss on ignition	16	--	--	--	--	14	15	--
MBAS	.04	.04	--	--	--	--	--	--
B.O.D.	--	--	--	--	--	--	--	3.4

Continued

TABLE 9. (Continued)

	ABOVE LOWELL		BELOW CONCORD RIVER AT LOWELL					WEST NEWBURYPORT
	1972	1973	1966	1968	1969	1970	1971	1973
C.O.D.	--	11.6	--	--	--	--	--	
D.O.	--	9.0	--	--	--	--	--	9.1
Alkalinity	21	6.4	--	--	--	--	--	--
Turbidity (JTU)	5.2	3	--	--	--	--	--	--
Oil & Grease	10	--	--	--	--	--	--	--
Chlorophyll A	5.58	--	--	--	--	--	--	--
CN	.02	--	--	--	--	--	--	--

Source: U.S.G.S. Water Resources Data, 1966-73 data on additional parameters (excluding toxic heavy metals) which have been measured primarily in the Merrimack River.

In general, the Merrimack River and tributary streams appear to be burdened by a heavy load of domestic and industrial wastes. Dissolved oxygen levels [5.0 ppm are required for a diverse fish population (Ellis, 1937)] are marginal or substandard over much of the watershed. The B.O.D. levels indicate high organic loading, according to the criteria (see page 69) developed by James (1965). In the tributary streams pH is fairly stable but fluctuates somewhat in mainstem waters. Levels of total phosphorous in the watershed were generally above levels required to support nuisance algal blooms (0.1-0.05 ppm, National Technical Advisory Commission, 1968). Nitrates appear to be in abundant supply [generally ≯0.03 ppm, as N, a level known to support nuisance algal growth in the presence of sufficient phosphorous (Mackenthun, 1965; Sawyer, 1970)]. Only the Squannacook River exhibits nutrient levels which could be considered limiting to excessive algal production (Figure 11). Although heavy metals will be discussed later, it should be pointed out that levels of cadmium, copper, and mercury detected in the Merrimack River are in excess of those considered acceptable by the Environmental Protection Agency (1973).

A detailed discussion of water quality in the Massachusetts section of the Merrimack River basin is presented below.

1) DISSOLVED OXYGEN

Dissolved oxygen data compiled by the U. S. Department of the Interior in August, 1964. for the Merrimack River are presented in Table 10. Most of these values were below 5.0 ppm, with the lowest concentrations occurring from Lawrence to Amesbury, Massachusetts (river miles 32.37 - 11.80, see Figure 11). More recent data obtained from U.S.G.S. records (1968 - 1971) at Lowell and West Newburyport are given in Figures 12 and 13, along with corresponding temperatures. As was true of the 1964 data, these data indicate only marginally acceptable levels of dissolved oxygen in the Merrimack River during the warmest months of the year.

Dissolved oxygen is not only one of the most important parameters to the well being of an aquatic community, but it is also one of the most widely variable parameters in a freshwater system. The condition of a lake or stream with respect to oxygen content is far more complex than would appear from the examination of a few tables (the same

TABLE 10. DISSOLVED OXYGEN AND B.O.D.$_5$ IN MERRIMACK RIVER, AUGUST 1964

(Pahren, *et al.*, 1966)

RIVER MILE	TEMP (°C)	D.O. (ppm) MIN	D.O. (ppm) $\bar{X}$	D.O. (ppm) MAX	B.O.D.$_5$ (ppm) MIN	B.O.D.$_5$ (ppm) $\bar{X}$	B.O.D.$_5$ (ppm) MAX	LOCATION	
48.76	21.9	3.4	5.0	8.0	3.8	4.5	5.0	Station 1	Foot of Lakeview Avenue
47.35								Station 2	Tyngsboro Bridge
46.20	21.8	3.1	5.1	6.9	2.4	4.5	7.2	Station 3	
43.47	21.4	3.2	4.1	5.3	2.0	3.1	4.6	Station 4	Lowell H_2O intake
37.45	21.6	1.5	3.2	4.9	5.0	5.6	6.3	Station 5	
36.53	21.7	1.3	2.8	4.9	4.6	5.0	5.3	Station 6	
35.00	21.7	1.1	2.6	4.3	3.6	4.5	5.7	Station 7	Power LInes
33.90	21.8	1.2	2.1	3.2	3.0	3.9	5.6	Station 8	Foot of Wheeler Street, Methuen, Massachusetts
32.37	21.9	0.9	2.1	3.8	2.7	3.2	4.3	Station 9	Merrimack Park Drive In, Methuen
31.60	21.9	1.5	2.4	3.5	2.9	3.1	3.4	Station 10	I-93 Bridge
29.81	21.9	0.8	2.3	3.0	2.4	3.1	3.9	Station 11	Lawrence H_2O intake
26.45	21.9	2.6	3.3	4.0	6.0	7.6	11.3	Station 12	
23.43	21.8	1.0	2.3	3.2	6.7	8.5	11.0	Station 13	
20.20	21.8	0.6	1.9	3.7	4.6	6.7	8.0	Station 14	Foot of Maxwell Street, Haverhill, Massachusetts
15.40	22.2	0.0	1.0	2.3	4.0	6.4	8.7	Station 15	Boat Dock, Haverhill Riverside Airport
13.47	22.2	0.0	0.9	2.5	4.7	6.6	7.7	Station 16	Buoy 49, near Pleasant Street, West Newburyport
11.80	22.0	0.2	1.6	3.2	3.3	6.1	8.0	Station 17	Rocks Village Bridge
10.36								Station 18	Buoy 37
6.92	21.1	1.0	2.5	5.0	1.5	4.7	7.0	Station 19	Foot of Martin Road, Amesbury
5.50	20.0	1.0	3.6	6.9	1.0	3.6	6.7	Station 20	I-95 Bridge
2.94	18.1	1.7	5.1	8.4	1.0	2.7	4.3	Station 21	B & M Railroad Bridge

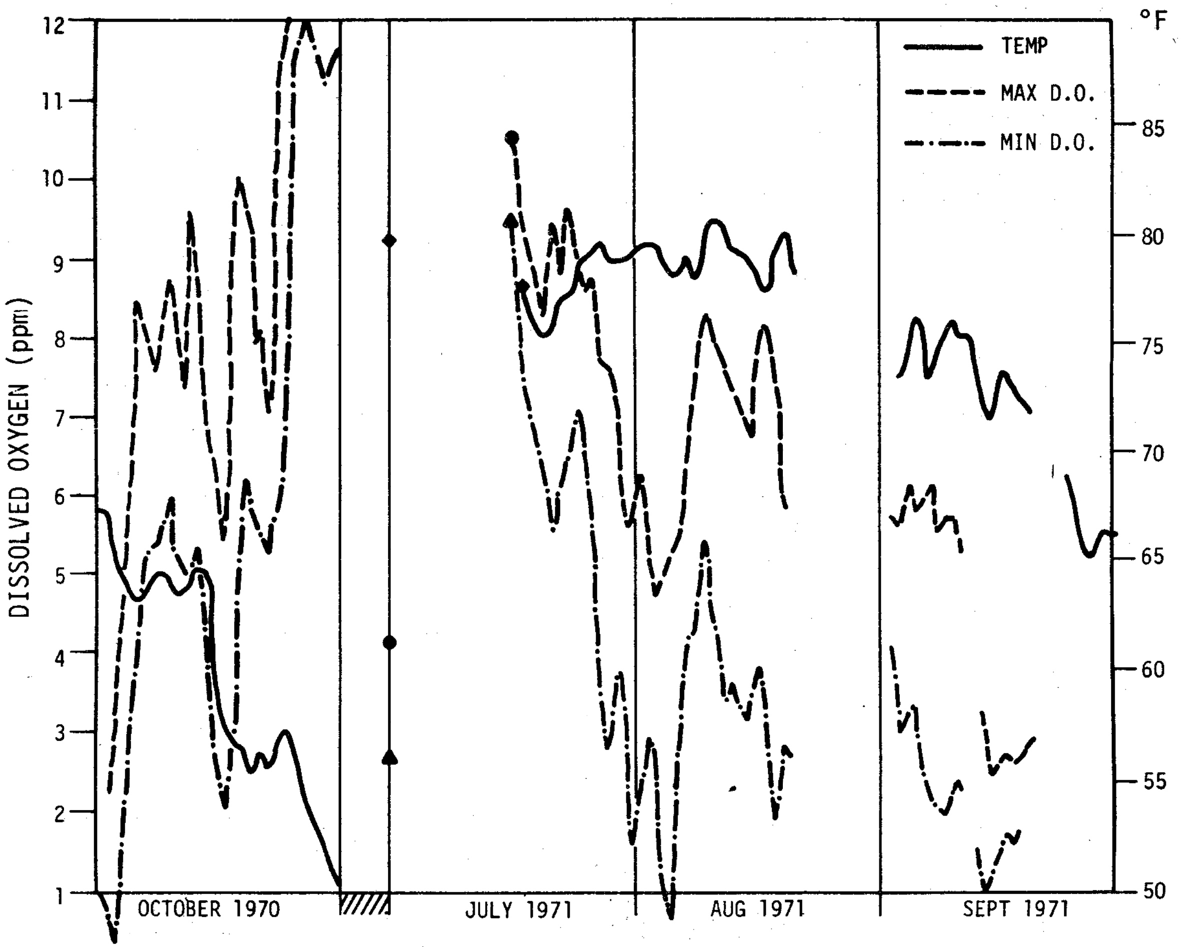


Figure 12. Levels of dissolved oxygen observed in the Merrimack River at West Newburyport during peak stress periods of the "Water Year" (U.S.G.S. Water Resources Data, 1971).

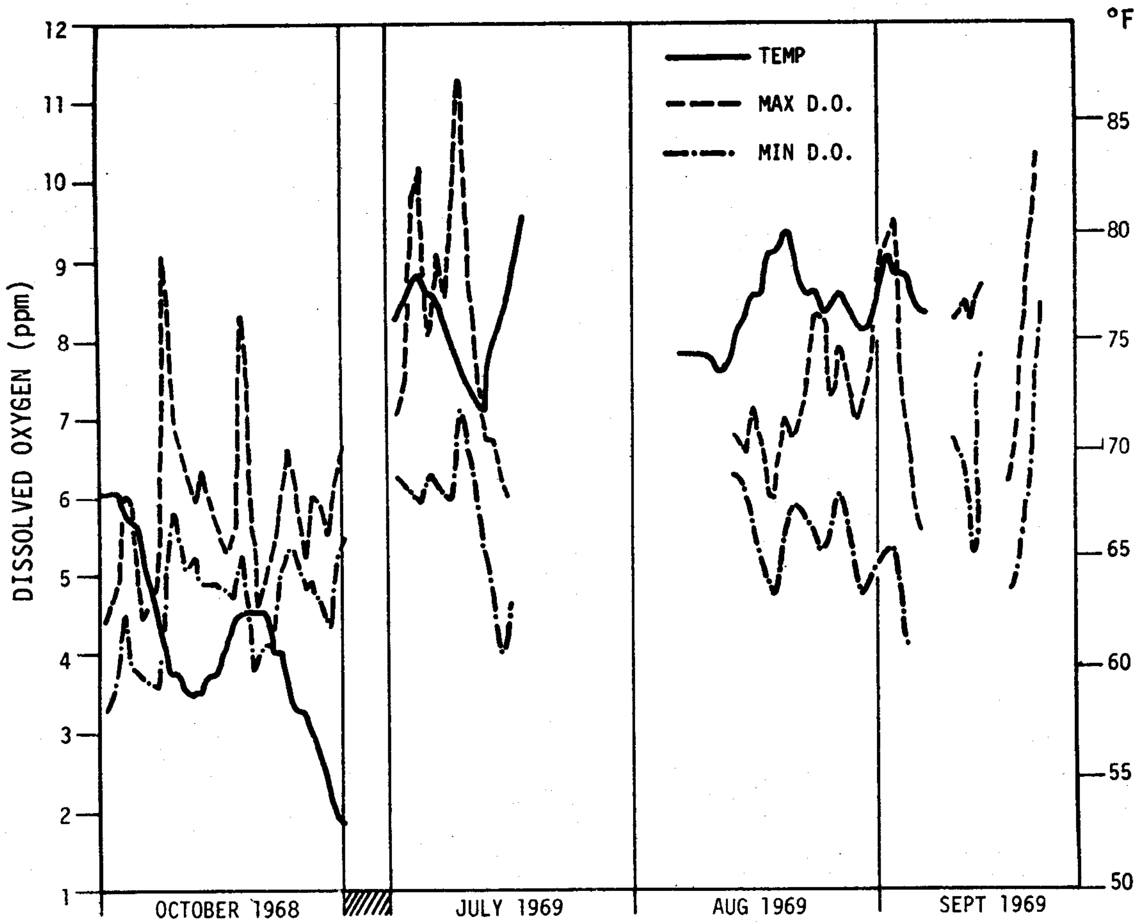


Figure 13. Levels of dissolved oxygen observed in the Merrimack River at Lowell, Massachusetts during peak stress periods of the "Water Year" (U.S.G.S. Water Resources Data, 1969).

could be said for most nonconservative substances in water). Figures 12 and 13 illustrate this point very well; complicated as the figures may seem at finest, certain events relating to dissolved oxygen concentration can be more easily demonstrated using these two figures rather than tables. For example, the rapid rise (October 1970) in oxygen content seen in Figure 12 is characteristic of a response which might have been the result of cooling water temperatures and strong autumn winds blowing across the water surface. The other peaks and valleys in the daily oxygen curves of Figures 12 and 13 are due to the combined effects of wind force, temperature and advective forces (currents). Smaller perturbations, caused by biological oxygen exchange activity (e.g. respiration and photosynthetic production), are encompassed within the daily minimum and maximum limits.

Since high temperatures reduce the solubility of gases in water, values generally sag to their lowest levels during the warmest part of the year. The river location with the deepest oxygen sag (Figure 12) also has the widest variation in oxygen content (compared to Figure 13). What is important to note here is that dissolved oxygen levels during periods of peak temperature stress, exhibit marked fluctuations (the result of complex biological, physical and chemical interactions). Such fluctuations would be observed even in a healthy (unpolluted) aquatic system; however, the large differential between the high and low values evident, especially in Figure 12 indicates a polluted environment which is highly unpredictable in available oxygen, and, therefore, is unsuitable for a diverse aquatic community.

Dissolved oxygen levels observed by Jerome *et al.* (1965) in the Merrimack Estuary ranged from 5.0 ppm to 10.0 ppm. Levels near the mouth of the estuary were higher and less variable than inshore levels. The mean for the whole system was 9.3 ppm. No critical oxygen problems were observed in the main body of the estuary, but levels were sometimes marginal in the transition zone between the freshwater and saline portion of the system.

Dissolved oxygen levels in tributary streams were quite variable. With the exception of the Squannacook River, which has the best conditions with respect to dissolved oxygen, oxygen levels recorded in recent years ranged from barely sufficient, to marginal, to insufficient for most aquatic organisms. Dissolved oxygen levels in the Shawsheen River in summer 1966 and 1968 are given in Tables 11 and 12, respectively. It appears that two areas of significant oxygen depletion occur in the Shawsheen River.

TABLE 11. TEMPERATURE, DISSOLVED OXYGEN, AND B.O.D.$_5$ IN SHAWSHEEN RIVER, 18-20 JULY, 1966

(Pahren, 1966)

RIVER MILE	TEMP °C			DISSOLVED O_2 (ppm)			B.O.D.$_5$ (ppm)			LOCATION
	MIN	AV.	MAX	MIN	AV.	MAX	MIN	AV.	MAX	
20.0	20.0	23.3	27.0	4.0	7.9	11.0	--	--	--	Route 62 Bridge, Bedford
18.11	20.0	22.8	26.0	2.1	5.4	8.0	1.2	1.6	2.3	Lowell Street Bridge, Bedford
16.7	20.0	22.3	25.0	0.8	3.5	6.4	1.3	1.6	1.9	Route 3A Bridge, Billerica
13.8	19.5	22.3	25.0	1.6	4.5	7.9	1.2	1.5	1.7	Route 129, Billerica-Wilmington
12.0	19.0	21.9	24.5	3.8	7.2	10.6	1.2	1.5	2.1	Main Street Bridge, Tewksbury
10.8	19.0	22.5	25.5	3.6	6.5	10.5	0.9	1.1	1.3	Lowe Street, Bridge, Tewksbury
7.6	20.0	23.8	26.5	0.7	1.6	2.7	2.5	3.1	3.7	Ballardville Bridge, Andover
5.6	20.0	23.3	25.5	1.4	3.3	6.3	1.1	1.1	1.2	Reservation Road Bridge, Andover
4.4	20.0	25.4	29.0	5.2	7.5	9.1	1.1	1.8	2.3	Route 28 Bridge, Andover
3.5	22.5	25.0	27.0	5.7	7.1	8.1	1.7	2.2	3.1	Kenilworth Street Bridge, Andover
2.5	20.5	24.7	28.0	6.3	8.1	9.9	--	--	--	Route 114 Bridge, North Andover
0.3	23.0	24.7	27.5	6.7	10.3	13.5	2.8	3.4	4.0	Sutton Street Culvert, Lawrence

TABLE 12. TEMPERATURE, DISSOLVED OXYGEN AND B.O.D.$_5$ IN SHAWSHEEN RIVER, 13-22 AUGUST, 1968

(Cooperman *et al.*, 1971)

RIVER MILE	TEMP °C MIN	AV.	MAX	DISSOLVED O_2 (ppm) MIN	AV.	MAX	B.O.D.$_5$ (ppm) MIN	AV.	MAX	LOCATION
26.1	11.7	15.0	18.9	8.5	9.2	9.5	1.3	2.2	3.0	Bedford - Hanscom Drive off Route 2A
22.7	16.1	17.8	21.1	6.0	8.6	11.1	2.2	2.6	2.8	Bedford - Old Billerica Road, Route 62
19.5	15.0	18.3	20.6	2.7	3.8	5.4	2.0	2.1	2.1	Billerica - Route 3A
12.8	14.4	17.8	19.4	4.3	5.9	8.3	1.1	1.8	2.6	Tewksbury - Lowe Street
10.6	14.4	12.8	20.0	4.7	5.9	7.7	0.7	1.6	2.1	Andover - Route 93
8.8	15.5	19.4	22.2	2.0	3.4	6.0	1.8	2.3	2.6	Andover - Ballardville at Andover St.
6.6	15.5	18.9	20.6	4.2	5.4	6.3	1.4	1.8	2.4	Andover - Horn Bridge
5.8	15.5	18.9	20.0	6.5	7.1	7.4	1.1	1.6	2.0	Andover - Essex Street Bridge
5.2	61.0	19.4	21.1	7.0	7.8	8.8	0.9	1.7	2.1	Andover - Route 28 Bridge
3.6	62.0	19.4	21.1	7.4	8.0	8.5	1.2	1.6	2.0	Andover - Railroad Bridge at rear of Raytheon
0.3	15.5	18.9	20.6	6.6	7.8	9.3	0.9	1.9	2.5	Lawrence - Merrimack Street Bridge

These two areas are from river miles 19.5 to 13.8 (Bedford, Billerica, Tewksbury), and from miles 8.8 to 5.6 (Andover) (see Figure 14). Dissolved oxygen data for the Powwow River are given in Table 13 and indicate marginal water quality conditions at the location sampled.

Dissolved oxygen concentrations appear to constitute a problem in the SUASCO System (Figure 15). Values observed in August, 1969, in the Assabet River (Cooperman and Jobin, 1971) exhibited a diurnal trend, with depressed values at night likely due to phytoplankton respiration, and higher values during the afternoons as a result of daytime photosynthetic activity. During the afternoon period, dissolved oxygen varied from 1.7 to 11.7 ppm with a mean value for the entire river of approximately 7.5 ppm. Late night hours produced dissolved oxygen concentrations ranging from 0.4 to 8.4 ppm with a mean value for the river course of 4.5 ppm. During periods of low flow in August, dissolved oxygen in the lower reaches of the Assabet rapidly became critical. Although some areas existed which maintained oxygen concentrations in excess of 5.0 ppm, these comprised only 30% of the 17 stations sampled. For the most part, the Assabet River does not maintain sufficient dissolved oxygen levels during late summer to support a diverse fish fauna.

Dissolved oxygen data from a 1973 summer survey of the Sudbury River (Massachusetts Water Resources Commission, 1973) also exhibited a diurnal pattern. The range for all stations was 0.0 to 7.9 ppm. From Ashland to Wayland on July 10-12, 1973, dissolved oxygen levels were generally marginal, ranging from 4.3 to 9.1 ppm with a mean of 6.3 ppm. Below Wayland a distinct drop in D.O. concentrations was experienced; levels ranged from 0.0 to 1.4 ppm with a mean value of 0.6 ppm. In late August, 1973, higher dissolved oxygen values were obtained in both the upper (above Wayland) and lower (below Wayland) Sudbury River. Above Wayland late August values ranged from 3.6 to 9.6 ppm with a mean of 6.5 ppm. Below Wayland the values ranged from 2.4 to 12.9 ppm with a mean of 5.4 ppm.

In July 1973 dissolved oxygen levels in the Concord River ranged from 1.1 to 7.7 ppm with a mean of 4.4 ppm (Massachusetts Water Resources Commission, 1973). Depressed values were observed from mile 10.5 to 5.2 (Carlisle, Bedford, Billerica). In August, the levels of dissolved oxygen increased, ranging from 4.9 to 12.2 ppm with a mean value of approximately 8.0 ppm. Dissolved oxygen levels observed in early July, 1965, (Water Quality

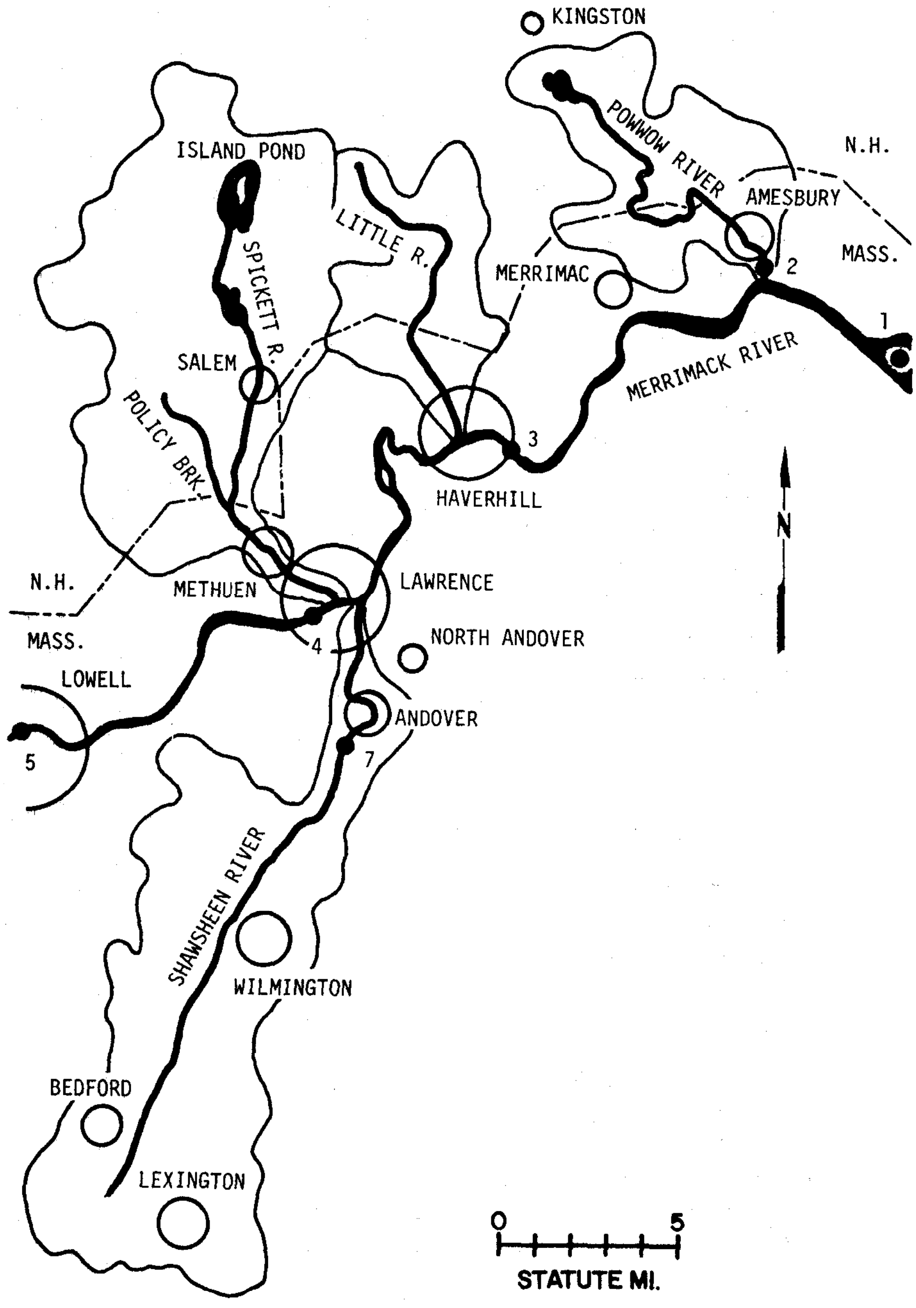


Figure 14. Merrimack, Shawsheen, and Powwow Rivers with Normandeau Associates, Inc. sampling stations indicated (modified from Pahren, 1966).

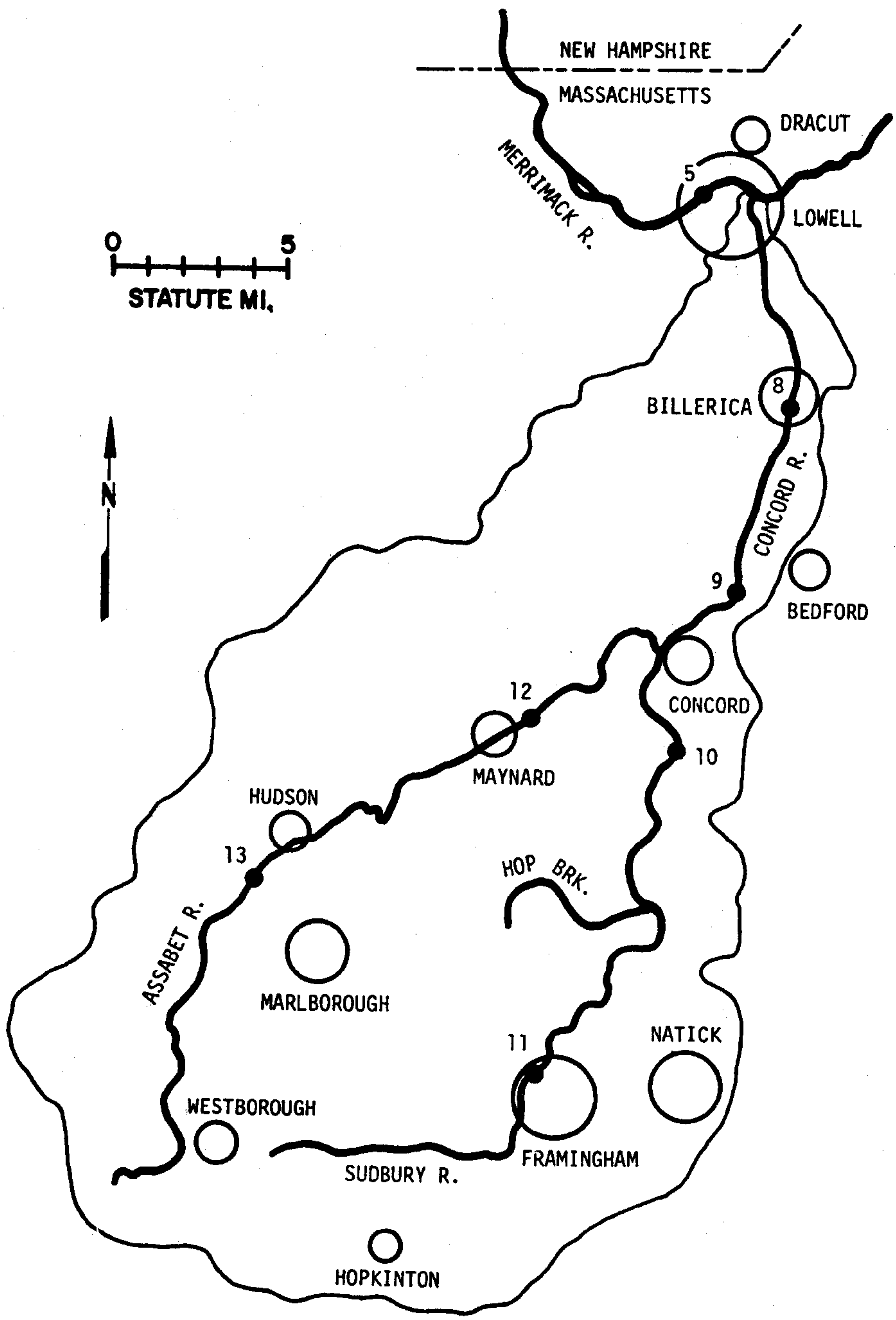


Figure 15. Sudbury, Assabet and Concord Rivers with Normandeau Associates, Inc. sampling stations indicated (modified from Pahren, 1966).

Management Section Division of Water Pollution Control, Massachusetts Water Resources Commission, 1973) ranged from 4.1 to 10.3 ppm with a mean value of 7.2 ppm.

Oxygen concentrations measured during the Merrimack River Basin field survey were of necessity gathered during the fall months (September and October, 1973) and therefore are not indicative of summer stress conditions. These data are presented in Appendix A for general information.

2) BIOCHEMICAL OXYGEN DEMAND (BOD)

BOD levels at stations along the Merrimack River are shown in Table 10. These values are occasionally quite high. James (1965) presents the following water classification based on BOD.

Very clean . . .	1 ppm BOD or less
Clean . . .	1 - 2 ppm BOD
Fairly clean . . .	2 - 3 ppm BOD
Doubtful . . .	3 - 5 ppm BOD
Bad . . .	10 ppm BOD

BOD of raw sewage before dilution is substantially higher. For example, raw sewage wastes from the towns of Maynard, Hudson, Shrewsbury, and Westboro, Massachusetts have a BOD range of 92 - 360 ppm (Cooperman, *et al.*, 1971). Headwaters of other rivers in Massachusetts have BOD values ranging from 0.5 - 2 ppm (e.g. Housatonic - 1.4 ppm, Charles - 0.5, Ten-Mile - 2.0; Cooperman, *et al.*, 1971). BOD values presented in Table 10 exhibit a mean value range from 2.7 - 8.5 ppm with a minimum value of 1.0 ppm and a maximum value of 11.3 ppm. These values, for the most part, are elevated over "natural background" values and, in conjunction with depressed oxygen values, indicate a significant input of organic material into the Massachusetts section of the Merrimack River. The present (1973) level of BOD in the Merrimack River at West Newbury is about 3.4 ppm (U.S.G.S. Water Resources, 1973). This indicates a decrease in organic loading since 1964, but the level is still greater than headwater values.

BOD values for the Shawsheen and Powwow Rivers are given in Tables 11, 12, and 13. According to the classification developed by James (1965), the Shawsheen River is fairly clean throughout its length, while the Powwow River exhibits a "doubtful" BOD level in its lower reaches.

During the 1969 state survey of the Assabet River (Cooperman and Jobin, 1971) increases in biochemical oxygen demand were noted below each major wastewater discharge. Near the headwaters of the river the background level of BOD was 2.2 ppm. Wastewater discharges from Westboro and Shrewsbury treatment plants raised this to 8.3 ppm and 6.0 ppm, respectively. No substantial increase was noted below the Marlborough treatment plant, but an increase to approximately 3.9 ppm was observed below the Hudson treatment plant. In each case, the input was local and the demand was satisfied rapidly by the stream.

BOD in the Sudbury River above Wayland in July, 1973, ranged from 2.2 to 3.6 ppm with a mean value of 2.2 ppm (Commonwealth of Massachusetts, Water Resources Commission, 1973). This is the same range as found for the headwaters of the Assabet River in 1969 (Cooperman and Jobin, 1971). Below Wayland in 1973, BOD ranged from 2.7 to 4.5 ppm, with a mean value of 3.65 ppm. In late August, 1973 BOD above Wayland ranged from 1.4 to 5.8 ppm with a mean of 3.03 ppm, showing an elevation over July levels. Below Wayland, BOD ranged from 2.4 to 7.5 ppm with a mean value of 5.3 ppm. Data from July, 1965, (Pahren, *et al.*, 1966) generally agree with above trends in dissolved oxygen, indicating fairly stable conditions in the Sudbury since at least 1965.

Biochemical oxygen demand levels observed in the July, 1973, survey of the Concord River ranged from 1.5 to 3.6 ppm, with a mean of 2.44 ppm. In August, these values were elevated -- ranging from 3.4 to 8.2 ppm with a mean of 5.56 ppm. Data taken in July, 1965, showed a range of 2.2 to 9.6 ppm and averaged about 4.7 ppm.

3) CHEMICAL OXYGEN DEMAND

Data on COD are only available for the Merrimack River. Above Lowell, in September 1971, COD ranged from 8-24 ppm (U.S.G.S. Water Resources Data, 1971). COD is generally higher than BOD since it includes refractory as well as biodegradable organic material. Raw sewage from the towns of Maynard, Hudson, and Westboro, Massachusetts have BOD loads between 129 and 324 ppm, whereas COD loads are from 257 - 890 ppm (Cooperman *et al.*, 1971).

4) NITROGEN

Levels of nitrogen compounds occurring at two locations in the Merrimack River from 1887 to 1972 are shown in Table 14. More complete data on nitrates and nitrites (as N) in July and August, 1972, are presneted in Table 15. Between 1908 and 1964, a drastic increase in ammonia, organic nitrogen and nitrate levels occurred. Concentrations of nitrate (NO_3^-) and nitrite (NO_2^-) are low upstream from Concord, New Hampshire. (NO_3^-) range: 0.31-0.42 ppm; (NO_2^-) range: 0.0-0.336 ppm. Concentrations increase sharply at Manchester, New Hampshire. In Massachusetts, nitrates are double their concentration at Concord, New Hampshire, and nitrites are an order of magnitude higher. Since nitrite is very unstable at low pH levels, such as those found in the Merrimack (discussed later), and under aerobic conditions quickly oxidizes to form nitrate, there must be a substantial nitrite input into the system and/or significant anaerobic conversion of nitrate to nitrite (Collier, 1972). Seasonal trends in total N, nitrate, and ammonia are shown in Tables 16, 17 and 18. Although data are scanty on total N and NO_3^-, build-ups of these nutrients are evident to some degree during periods of lower plant production (September - October).

Nitrogen compound levels in the tributaries are not well documented. Tables 19 and 20 present seasonal averages of available data regarding nitrate and ammonia levels in many of the tributaries. Table 21 gives more detail for at least two dates in August on ammonia, nitrite, and nitrate levels in the Shawsheen River. The nitrate values on these dates in 1968 over the course of this river ranged from 0.0 to 1.3 with a mean of 0.48, whereas U.S.G.S. data taken in 1973 indicated a range of 0.69 ppm to .89 ppm, with a mean of 0.79. It appears then that variability in nitrate levels has decreased, but mean levels are about 0.3 ppm greater.

In the Assabet River, levels of ammonia, as nitrogen, observed in July of 1965 (Water Quality Management Section, Division of Water Pollution Control, Massachusetts Water Resources Commission, 1973) generally ranged from 0.1 ppm to 0.6 ppm, with one value of 20.0 ppm. The mean value for the river was approximately 0.17 ppm. Levels of

TABLE 14. NITROGEN COMPOUNDS IN THE MERRIMACK RIVER ABOVE LOWELL AND LAWRENCE, MASSACHUSETTS, 1887-1972

YEARS	STATION	AMMONIA (as N)	ALBUMINOID OR ORGANIC (as N)	NITRATE (as N)
1887-1908[1]	Above Lowell	0.04	0.15	0.02
1887-1908[1]	Above Lawrence	0.10	0.19	0.02
1964-1965[1]	Above Lowell	0.80	1.92	0.50
1964-1965[1]	Above Lawrence	0.90	--	--
1967-1971[2]	Above Lowell	1.00	--	--
1967-1971[2]	Above Lawrence	0.95	--	--
1972[3]	Above Lowell	--	--	~0.50
1972[3]	Above Lawrence	--	--	~0.60

1 (Pahren, 1966)

2 (U.S.G.S. Water Resources Data, 1967-1971)

3 (Collier, et.al., 1972)

TABLE 15. NITRATE AND NITRITE CONCENTRATIONS IN THE MERRIMACK RIVER BASIN (JULY AND AUGUST, 1972)[2,3]

STATION	LOCATION	JULY 1972 NO_2[1]	JULY 1972 NO_3[1]	AUGUST 1972 NO_2[1]	AUGUST 1972 NO_3[1]
1	Echo Lake	.0028	.896	.0028	.952
2		.0035	.308	.0035	.308
3		0	.588	0	.532
3A		0	--	0	--
3B	East Branch, Pemigewasset River	0	.182	0	.252
3C		.0021	.308	.0021	.420
4		.0036	.280	.0035	.392
5	Plymouth, New Hampshire	.0036	.392	.0035	.392
6	Winnipesaukee River	.0021	.308	.08	.364
7	Franklin, New Hampshire	.0036	.366	.0028	.364
8		.0035	--	.0035	--
9		.0035	.252	.0035	.420
9A		.0056	.308	.0042	.392
10	Concord, New Hampshire	.0012	.420	.0042	.644
11		.007	.392	.0035	.392
12	Manchester, New Hampshire	.0105	.532	.0175	.784
13	Nashua, New Hampshire	.0105	.476	.021	.616
14	Lowell, Massachusetts	.0105	.588	.028	.616
15		.0105	.560	.0294	.868
16	Lawrence, Massachusetts	.0176	.756	.035	.924
17		.021	.700	.0257	1.12
18		.021	.784	.0364	1.286
19		.028	.728	.035	1.120
20		.0315	.812	.035	1.176
20A		.0294		.0259	--
21	Merrimack River Estuary	.0259		.0161	--

[1] As N (ppm)

[2] Modified from Collier, et.al., 1972.

[3] Stations without specific geographic locations indicated were situated between abutting station designations

TABLE 16. AVERAGE SEASONAL TRENDS IN TOTAL NITROGEN LEVELS (ppm) IN THE MERRIMACK RIVER ABOVE LOWELL, 1965-1973

(U.S.G.S. Water Resources Data)

MONTH	NO. OF SAMPLES	MEAN	RANGE
January	3	1.08	0.80-1.5
February	3	1.16	0.77-1.5
March	3	0.80	0.70-1.5
April	3	0.56	0.37-0.78
May	3	0.47	0.39-0.55
June	3	1.1	0.84-1.4
July	2	2.2	1.00-3.4
August	2	1.45	1.40-1.5
September	2	2.8	2.20-3.4
October	3	2.5	2.60-2.7
November	3	1.4	1.30-1.5
December	3	0.94	0.66-1.2

TABLE 17. SEASONAL NITRATE CONCENTRATIONS (PPM) IN THE MERRIMACK RIVER, 1965-1973

(U.S.G.S. Water Resources Data)

	ABOVE LOWELL			ABOVE AND BELOW CONCORD RIVER AT LOWELL			WEST NEWBURYPORT		
	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R
January	3	.23	.2-.3	6	3.95	2.2-6.5			
February	3	.27	.2-.3	4	2.13	.8-3.2	1	2.7	
March	3	.3	.2-.4	8	1.2	.3-4.4			
April	3	.2	.1-.3	5	1.4	0-4.6	2	.65	.7-.59
May	3	.16	.09-.2	4	.87	.5-1.7	1	.49	--
June	2	1.1	.6-2.7	4	.99	.4-1.8			
July	2	.5	.1-1.4	4	4.5	2.4-6.7			
August	3	.43	.1-.7	2	2.1	1.6-2.6			
September	3	.43	.4-.5	6	3.5	2-6.8			
October	3	.5	.4-.7	3	3.57	1.6-4.7			
November	3	.23	.2-.3	3	1.87	.3-3.4	1	.60	--
December	4	.22	.16-.31	4	1.55	.3-3.6			

N = Number of samples

$\bar{X}$ = Mean

R = Range

TABLE 18. SEASONAL AMMONIA CONCENTRATIONS (IN ppm) IN THE MERRIMACK RIVER, 1965-1973

(U.S.G.S. Water Resources Data)

	ABOVE LOWELL			ABOVE AND BELOW CONCORD RIVER AT LOWELL		
	N[1]	$\overline{X}$[2]	R[3]	N	$\overline{X}$	R
August	2	1.0	.9-1.1	2	.95	.9-1.0
September	---	---	---	3	1.32	.5-1.73
October	1	3.5	---	---	---	---
November	---	---	---	---	---	---
December	1	.18	---	---	---	---

N = Number of samples

$\overline{X}$ = Mean

R = Range

TABLE 19. SEASONAL NITRATE LEVELS (PPM) IN TRIBUTARY STREAMS OF THE MERRIMACK RIVER BASED ON STUDIES CONDUCTED DURING THE PERIOD 1965-1973

(Cooperman, Costello, and Jobin, 1971; Commonwealth of Massachusetts Water Resources Commission, 1973; U.S.G.S. Water Resources Data, 1973)

	SHAWSHEEN			POWWOW	CONCORD			ASSABET			SUDBURY			SQUANNACOOK
	N	$\bar{X}$	R	$\bar{X}$	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R	$\bar{X}$
January														
February														
March														.20[1] --
April	5	.79	.69-.89	.01[1]										
May														
June														
July					13	.21	.1-.3	2	.45	.4-.5	28	.2	0-.5	
August					10	.41	.2-.5	2	.95	1.0-.9	20	.29	0-.5	

N = Number of samples $\bar{X}$ = Mean R = Range [1] single sample only

TABLE 20. OBSERVED AMMONIA CONCENTRATIONS (PPM) IN TRIBUTARY STREAMS OF THE MERRIMACK RIVER BASED ON STUDIES CONDUCTED DURING THE PERIOD 1965-1973

(Cooperman, Costello, and Jobin, 1971; Commonwealth of Massachusetts Water Resources Commission, 1973; U.S.G.S. Water Resources Data, 1973)

	CONCORD			ASSABET			SUDBURY			SQUANNACOOK	
	N	$\overline{X}$	R	N	$\overline{X}$	R	N	$\overline{X}$	R	N	$\overline{X}$
January											
February											
March											.10[1] --
April											
May											
June											
July	13	.14	.1-.12	2	.10	.09-.12	26	.133	0-.3		
August	10	.168	0-.58	2	.06	.03-.08	20	.127	0-.32		

N = Number of samples $\overline{X}$ = Mean R = Range [1]Single sample only

TABLE 21. CONCENTRATION OF AMMONIA, NITRITE, AND NITRATE[1] IN THE SHAWSHEEN RIVER - AUGUST, 1968

RIVER MILE	13 AUGUST 1968 AMMONIA (PPM)	NITRITE (PPM)	NITRATE (PPM)	20 AUGUST 1968 AMMONIA (PPM)	NITRITE (PPM)	NITRATE (PPM)
20.0	.05	.006	.9	.03	.005	1.2
18.1	.04	.008	.8	.03	.009	1.0
16.7	.17	.013	.6	.35	.016	1.3
13.8	.08	.001	.3	.04	.006	1.3
12.0	.05	.004	.0	.04	.004	1.0
10.8	.07	.010	.0	.05	.007	.0
7.6	.10	.016	.1	.10	.017	.3
5.6	.10	.012	.1	.06	.010	.3
4.4	.17	.011	.1	.06	.006	.3
3.5	.09	.009	.1	.08	.011	.2
2.5	.06	.011	.2	.03	.006	.2

1 from Cooperman, Costello, and Jobin (1971)

nitrite, as nitrogen, ranged from 0.1 ppm to 0.5 ppm with a mean value of 0.25 ppm. Nitrite levels did not show a direct relationship to wastewater input.

Ammonia levels in the Sudbury River are presented in condensed form in Table 22.

TABLE 22. AMMONIA AND NITRATE LEVELS IN THE SUDBURY RIVER

(Commonwealth of Massachusetts, Water Resources Commission, 1973)

LOCATION	DATE	AMMONIA-N (ppm) Mean	AMMONIA-N (ppm) Range	NITRATE-N (ppm) Mean	NITRATE-N (ppm) Range
Above Wayland	July 1973	0.07	0.00-0.18	0.25	0.10-0.40
	August 1973	0.08	0.00-0.43	0.25	0.00-0.50
Below Wayland	July 1973	0.16	0.07-0.30	0.05	0.00-0.10
	August 1973	0.19	0.03-0.32	0.35	0.10-0.50

The area below Wayland received appreciably more ammonia than the area above Wayland. Substantial differences in nitrogenous input existed between those portions of the river above Wayland and those below Wayland. Nitrate levels observed in the Sudbury River are presented in Table 22.

Ammonia levels in the Concord River ranged from 0.10 to 0.22 ppm in July, 1973, with a mean of 0.16 ppm. In August, this level was slightly higher, ranging from 0.00 to 0.59 ppm with a mean value of 0.17 ppm. Nitrate levels in July, 1973, ranged from 0.1 to 0.3 ppm with a mean of 0.2 ppm. In August, nitrate levels increased, ranging from 0.2 to 0.5 ppm and averaging 0.42 ppm.

Levels of ammonia in all rivers considered were consistently above EPA (1973) criteria of 0.02 ppm, and levels of NO_3 were generally above 0.3 ppm, a level which appears to be the critical point for algal blooms (Mackenthun, 1965; Jaworski *et al.*, 1969; Sawyer, 1970) if sufficient phosphorous is present.

5) PHOSPHOROUS

Phosphorous, like nitrogen, occurs in several forms in the ecosystem (see Figure 7). Orthophosphate (soluble PO_4) in particular has been implicated in nuisance algal blooms and "cultural eutrophication". Average seasonal levels of total P and PO_4 observed in the Merrimack River are shown in Tables 23 and 24. Additional data on the Merrimack River is presented in Table 25.

In 1964 and 1965, orthophosphate levels in the upper reaches of the Merrimack River ranged from 0.065 to 0.0293 ppm with a mean of 0.0130. Lower stretches (below Manchester, New Hampshire) ranged from .0652 to 0.2738 ppm with a mean of 0.1467 ppm (as P; data from Pahren *et al.*, 1966). These values are comparable to PO_4 values observed during a 1972 survey (Collier, *et al.*, 1972) in which, levels in the upper reaches of the Merrimack in 1972 ranged from 0 to .0248 ppm with a mean of 0.0060 ppm (as P). Below Manchester, New Hampshire, levels ranged from .015 to .148 ppm with a mean of .08 ppm.

Seasonal levels of total P and PO_4 in the Merrimack tributaries are given in Tables 26 and 27, and greater detail on summer phosphorous levels is given in Table 28. for the Shawsheen River.

Recent data (U.S.G.S., April, 1973) on the Shawsheen River shows a range of total phosphorous of 0.05 to 0.33 ppm, with a mean of 0.13 ppm. Total phosphorous in August 1968 ranged from 0.07 to 0.33 ppm, with a mean of 0.17 ppm. U.S.G.S. data for the Squannacook River (March, 1973) indicated a total phosphorous level of 0.017 ppm. In the Powwow River, elevated levels of phosphorous were evident; total phosphorous levels at Mile 7.2 were 0.24 ppm, and 1.00 ppm at Mile 0.7 (Pahren *et al.*, 1966). U.S.G.S. data for April, 1973, indicated slightly lower levels for this river (0.19 ppm as phosphate).

In the SUASCO system, phosphorous levels were quite high at certain localities. Phosphate concentrations (as P) in the Assabet River showed a direct response to waste water input. Beyond sources of waste input,

TABLE 23. OBSERVED TOTAL PHOSPHOROUS CONCENTRATIONS (PPM) IN THE MERRIMACK RIVER BASED ON STUDIES CONDUCTED DURING THE PERIOD 1965-1973

(U.S.G.S. Water Resources Data, 1966-1973)

	ABOVE LOWELL			ABOVE AND BELOW CONCORD RIVER AT LOWELL			WEST NEWBURYPORT
	N	$\bar{X}$	R	N	$\bar{X}$	R	
January	3	.11	.097-1.4	--	--	--	--
February	3	.12	.077-.18	--	--	--	--
March	3	.095	.086-.10	2	.17	.14-.2	--
April	3	.075	.042-.12	1	.093	--	.10[1]
May	3	.052	.05-.055	--	--	--	.13[1]
June	3	.087	.073-.10	1	.10	--	--
July	2	.15	.12-.18	--	--	--	--
August	2	.215	.19-.29	--	--	--	--
September	2	.215	.19-.29	2	.245	.20-.29	--
October	3	.17	.13-.19	--	--	--	--
November	3	.147	.12-.17	1	.21	--	.40[1]
December	3	.122	.056-.19	1	.13	--	--

N = Number of samples $\bar{X}$ = Mean R = Range [1] = Single sample only

TABLE 24. PHOSPHATE CONCENTRATIONS (PPM AS P) IN MERRIMACK RIVER BASED ON STUDIES CONDUCTED DURING THE PERIOD 1965-1973

(U.S.G.S. Water Resources Data, 1966-1973)

	ABOVE LOWELL			ABOVE AND BELOW CONCORD RIVER AT LOWELL			WEST NEWBURYPORT		
	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R
January				4	.75	.17-1.7			
February				4	.298	.13-.67			
March	1	.31	--	7	.18	.02-.43			
April	1	.15	--	3	.106	.05-.2	2	.085	.07-.10
May	1	.17	--	4	.47	.32-.89	1	.15	--
June	1	.27	--	1	.1	--			
July	1	.36	--	4	.18	.01-.2			
August	1	.39	--	1	.44	--			
September	2	.46	.34-.58	4	.34	.19-.61			
October				3	.87	.42-1.3			
November	1	.58	--	2	.47	.46-.48			
December	2	.28	.19-.37	2	.665	.44-.89			

N = Number of samples $\bar{X}$ = Mean   R = Range

TABLE 25. PHOSPHATE CONCENTRATIONS (PPM AS P) IN THE MERRIMACK RIVER (JULY AND AUGUST, 1972).

STATION	LOCATION	JULY 1972 PO_4	AUGUST 1972 PO_4
1	Echo Lake	.0062	.0031
2 [2]		.0093	.0062
3		.0031	.0031
3A		0	0
3B	East Branch Pemigewasset River	0	0
3C		0	0
4		0	0
5	Plymouth, New Hampshire	.0217	.0248
6	Winnipesaukee River	.0062	.0093
7	Franklin, New Hampshire	.0062	.0093
8		.0062	.0093
9		.0062	.0062
9A		.0093	.0093
10	Concord, New Hampshire	.0093	.0124
11		.0093	.0248
12	Manchester, New Hampshire	.062	.0155
13	Nashua, New Hampshire	.062	.031
14	Lowell, Massachusetts	.0465	.0465
15		.0589	.0713
16	Lawrence, Massachusetts	.0713	.1023
17		.0744	.1475
18		.1054	.1085
19		.093	.0744
20		.0868	.0868
20A		.093	.0806
21	Merrimack Estuary	.0496	.1023

[1] Modified from Collier, et.al., 1972.

[2] Stations without specific geographic locations indicated were situated between abutting stations designations

TABLE 26. TOTAL PHOSPHOROUS CONCENTRATIONS (PPM) IN MERRIMACK RIVER TRIBUTARIES, 1965-1973

(Cooperman and Jobin, 1971; Commonwealth of Massachusetts Water Resources Commission, 1973; U.S.G.S. Water Resources)

	SHAWSHEEN			POWWOW		CONCORD			ASSABET			SUDBURY			SQUANNACOOK	
	N	$\overline{X}$	R	N	$\overline{X}$	N	$\overline{X}$	R	N	$\overline{X}$	R	N	$\overline{X}$	R	N	$\overline{X}$
March															1	.017
April	5	.13	.057-.18	1	.019											
May																
June																
July						10	.24	.21-.27	2	.23	.22-.24	20	.24	.02-1.0		
August	33	.17	.07-.33			10	.22	.17-.38	2	.265	.26-.27	20	.135	.01-.30		

N = Number of samples $\overline{X}$ = Mean R = Range

TABLE 27. PHOSPHATE CONCENTRATIONS (PPM AS P) IN MERRIMACK RIVER TRIBUTARIES BASED ON STUDIES CONDUCTED DURING THE PERIOD 1965-1973

(Cooperman and Jobin, 1971; Commonwealth of Massachusetts. Water Resources Commission, 1968, 1973; U.S.G.S. Water Resources Data, 1973)

	SHAWSHEEN			POWWOW			CONCORD			ASSABET			SUDBURY		
	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R	N	$\bar{X}$	R
April	5	.198	.02-.49	1	.01	--									
May															
June							7	.68	.54-.86	12	1.74	.04-5.26	5	.29	.04-.86
July							3	.47	.3-.7				6	.45	.1-.7
August	40	.09	0-1.5												

N = Number of samples $\bar{X}$ = Mean R = Range

TABLE 28. TOTAL PHOSPHOROUS CONCENTRATIONS OBSERVED IN SHAWSHEEN RIVER - AUGUST 1968 AND JULY 1966

RIVER MILE	AUGUST 1968[1] TOTAL PHOSPHOROUS (PPM)	JULY 1966[2] TOTAL PHOSPHOROUS (PPM)
20.0	0.08	--
18.1	0.11	0.11
16.7	0.17	0.43
13.8	0.14	0.17
12.0	1.20	0.18
10.8	0.17	0.56
7.6	0.26	0.93
5.6	0.22	1.07
4.4	0.19	0.60
3.5	0.19	1.06
2.5	0.23	--
0.3		0.21

1 Cooperman, Costello, and Jobin (1971) Mean Value

2 Pahren (1966)

concentrations of phosphate dropped rapidly, indicating rapid metabolic uptake. Levels of PO_4 ranged from 0.07 ppm to 3.05 ppm (Cooperman and Jobin, 1971).

Phosphate levels were measured on the Assabet River, from the headwaters to the confluence with the Sudbury River, Cooperman and Jobin (1971). Above Westborough, levels of 0.07 and 0.13 ppm were observed. Conditions worsened below the Westborough sewage treatment plant; at this point phosphate levels rose to 2.15 ppm. The Shrewsbury effluent raised the level to 3.05 ppm. In impounded areas, the phosphate content was lower (0.55 ppm) apparently through biological uptake and loss to bottom sediments. With the addition of sewage from the town of Hudson, the amount of phosphate increased to 1.6 ppm. Beyond this point the river slowed again, and phosphate decreased (0.38 ppm measured in the Stow area). The Maynard effluent caused a slight increase (to 0.68 ppm). The level at the confluence of the Assabet and Sudbury Rivers was 0.44 ppm (measured in summer 1973) (Commonwealth of Massachusetts, Water Resources Commission, 1973).

Levels of total P in the Sudbury River (Commonwealth of Massachusetts, Water Resources Commission, 1973) exhibited an increase below Wayland in both July 1973 and late August 1973. Levels in late August, however, were lower than July values. Above Wayland, in July, the total phosphorous above Wayland ranged from 0.01 to 0.29 ppm and averaged 0.096 ppm. Levels below Wayland ranged from 0.15 to 0.30 ppm, with a mean value of 0.195 ppm. The area above Wayland receives sewage wastes at discrete points, and the total amount of phosphorous delivered is rapidly raken up. Below Wayland, phosphorous sources are large, and closely spaced, and the river community always has an abundant supply of phosphorous.

Levels of total P present in the Concord River, July 1973, ranged from 0.21 to 0.26 ppm, with a mean of 0.24 ppm. With increased primary production in August 1973, levels dropped to between 0.17 to 0.38 ppm (mean = 0.21 ppm) (Commonwealth of Massachusetts, Water Resources Commission, 1973).

6) pH

Values measured by the United States Geological Survey, Water Resources Division, on the Merrimack River at Lowell, Massachusetts, from 1967 through 1972, ranged from

5.6 to 8.9 with a mean of 6.77. Values for the colder months were lower than for the highly productive, warmer months. Comparable data from the same source (1968 - 1972) for West Newburyport indicated a similar range (5.4 - 8.6) and mean (6.55). In the Merrimack River estuary, pH values ranged from 7.0 to 8.5 near the mouth with a mean of 8.0. Upstream stations had lower pH's (6.5-8.0; mean = 7.0).. In the Squannacook River, during August 1968, pH ranged from 6.6 to 7.5 (Cooperman *et al.*, 1971). The mean during that time period was 7.1. Other tributaries in the system (viz. Assabet, Sudbury, Concord) had mean pH's of between 6.8 and 7.3 in summer, 1973; highest values were observed in the Concord River. Observed ranges of pH in July-August, 1973, in the SUASCO system were: 6.6-7.1, Assabet River; 6.5-7.3, Sudbury River; and 7.1-7.6, Concord River (Commonwealth of Massachusetts, Water Resources Commission, 1973).

7) ALKALINITY

Hardness and alkalinity are related in the sense that total alkalinities in the range of 40 ppm seem to be the breaking point between "soft" and "hard" waters (Moyle, 1949 in MacKenthun and Ingram, 1967). Little alkalinity data is available for the Merrimack River.

Alkalinities were measures however in the Sudbury, and Concord Rivers, and these were in the realm of "soft" waters comparatively speaking. In the Sudbury River, in July and August 1973, alkalinities ranged upwards to 2.8 ppm, with higher values being recorded in downstream reaches. In July, the mean upstream value was 16 ppm, while the mean downstream concentration was 22 ppm. In August, a similar situation was observed (18 vs 28 ppm), indicating a greater "buffering" capacity in downstream, marshy, environments. Alkalinity levels measured in the Concord River were comparable to those of the lower Sudbury River, and ranged from 23 to 25 ppm in July (mean = 23 ppm), and 25 to 27 ppm in August (mean - 26 ppm) (Commonwealth of Massachusetts, Water Resources Commission, 1973).

8) MAJOR CATIONS

Major cationic constituents in river systems are calcium (Ca), sodium (Na), potassium (K), and magnesium (Mg). Data from the Merrimack River indicate a range for calcium from 4.6 to 7.1 ppm; a range for sodium from 10.1 to 13.3 ppm; a range for potassium from 0.8 to 1.5 ppm; and a range for magnesium from 0.8 to 1.3 ppm (U.S.G.S. Water Resources Data, 1966 - 1973). The Squannacook River, in contrast, appears to have lower cationic levels, although data are only available for March 1973. Levels of cations in the Squannacook then were: 2.8 ppm, calcium; 5.3 ppm, sodium; 0.6 ppm, potassium; and 0.5 ppm, magnesium (U.S.G.S. Water Resources Data, 1966-1973).

9) METHYLENE BLUE ACTIVE SUBSTANCES

The test for MBAS indicates the presence of surfactants (surface active agents) in the water. Surfactants are substances which serve as "wetting agents" in detergents, lowering the surface tension and permitting floatation of dirt particles. LAS (linear alkyl sulfonate) is the most common of these, having replaced the foam-producing and non-biodegradable ABS (alkyl benzene sulfonate). LAS does not foam apparently, but some concern is expressed over possible phenol residue toxicity. MBAS concentrations in the range of approximately 0.4 ppm have been reported in the Merrimack River (Jerome, *et al.*, 1965; U.S.G.S. 1973). Jerome *et al.* (1965) found 0.0 to 0.2 ppm at stations at the mouth of the Merrimack estuary, and 0.1 to 0.5 ppm upstream. Recent (1973) U.S.G.S. measurements in the river above Lowell, Massachusetts, indicated concentrations of 0.4 ppm.

10) TOXIC NON-METALS

Potentially toxic non-metals of importance include such things as phenols, pthalate esters, oil and grease, flouride, organophosphates (pesticides and herbicides), and chlorinated hydrocarbons (pesticides, PCB's). Phenols, pthalates and oil, and grease have not been well-studied in the Merrimack watershed. Flouride levels in the Merrimack River have ranged from 0.1 to 0.4 ppm over recent years, with highest concentrations observed above Lowell, Massachusetts, in 1973. In contrast, the Squannacook River at Shirley, Massachusetts had 0.1 ppm in March 1973 (U.S.G.S. Water Resources Data, 1966-1973).

11) <u>CHLORINATED HYDROCARBONS</u>

Chlorinated hydrocarbons, including polychlorinated biphenyls (PCB's) and pesticides, have a much stronger affinity for fatty and oily substances than for water; consequently chlorinated hydrocarbons reside for only a short time in the water column. However, water samples taken from the Merrimack River Estuary, which were tested in June and July, 1964, showed measurable levels of pesticides (Table 29).

TABLE 29. PESTICIDE CONCENTRATIONS IN WATER SAMPLES TAKEN AT NEWBURYPORT AND SALISBURY, SITES P_1 AND P_2, MERRIMACK RIVER ESTUARY, 1964

(Jerome *et al.*, 1965)

DATE COLLECTED	SAMPLE SITE	HEPTACHLOR EPOXIDE (PPM)	DIELDRIN* OR DDE (PPM)	DDT (PPM)
June 17	P_1	No Test	0.001	0.001
17	P_2	No Test	0.001	0.001
July 10	P_1	0.002	None	0.003
10	P_2	0.001	None	0.001
July 20	P_1	0.005	No Test	0.002
20	P_2	0.006	No Test	0.002
July 30	P_1	0.001	None	0.002
30	P_2	0.001	None	0.002

*Dieldrin--DDE: Not separable by method used.
P_1= Newburyport Sewage Treatment Plant, P_2= Coffin Point.

DDT and Heptachlor Epoxide were present in all water samples tested: DDE and/or Dieldrin was present in two of the six water samples tested.

Chlorinated hydrocarbons are rapidly taken up in the fatty tissues of living organisms or find their way in to the sediments. A discussion of pesticide and PCB levels in finfish, and pesticide levels in mud samples of the Merrimack estuary, will be included in later sections.

12) METALS

Concentrations of metals in the Merrimack River are shown in Table 30. Calcium (Ca), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), molybdenum (Mo), selenium (Se), sodium (Na), vanadium (V), and zinc (Zn) are metals needed for normal growth and reproduction of plants in trace amounts. Aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), lead (Pb), mercury (Hg), nickel (Ni), silver (Ag), and tin (Sn) are not considered essential to normal plant function, but as is true of all the listed metals, may be toxic in high concentrations.

Aluminum is the most abundant metal, comprising eight percent of the earth's crust. It never appears in its pure state in nature, however. The single observed value of 300 ppb is well within natural background levels for United States waters on the whole [12 - 2550 ppb (Bahr, 1968)]. Observed levels of other metals, such as cadmium, arsenic, copper, lead, manganese, cadmium and nickel, are also within the range of natural "background levels" reported by Bahr (1968). Some, however, do approach the upper limits of these background levels -- namely arsenic (7 ppb vs <10 ppb); lead (0.5 - 50 ppb vs 0 - 40 ppb); cadmium (6 ppb vs 0 - 10 ppb); and maganese (20 - 108 ppb vs 0 - 140 ppb). Mercury and zinc, two metals which can be highly toxic, were found in unusually high amounts in the Merrimack River (Mercury: 4.7 ppb vs 0.002 - 0.70 ppb natural background; zinc: 4 - 73 ppb vs <5 - 10 ppb natural background). Metals such as barium, chromium, cobalt, and iron, did not occur in outstanding quantities when compared to "background levels" of U. S. waters, yet concentrations of iron for example, were above human taste thresholds and fish toxicity thresholds. While the concept of natural background levels may be useful, many other parameters influence the behavior and toxicity of metals (e.g. pH, alkalinity, temperature). More elaboration on toxicities of metals will be given in subsequent sections of this report.

Little data are available on metal contamination of tributary streams in the Merrimack Watershed. The Sudbury River had the following concentrations of metals in 1971 (U.S.G.S.).

TABLE 30. TOXIC METALS IN THE MERRIMACK RIVER[1]

(U.S.G.S. Water Resources Data, 1966-1973)

METAL	ABOVE LOWELL	BELOW CONCORD RIVER AT LOWELL	WEST NEWBURYPORT
Aluminum	300 (1973)	----	----
Antimony	----	----	----
Arsenic	0 (1970) 7 (1973)	0 (1970)	----
Barium	13 (1973)	----	----
Beryllium	0 (1973)	----	----
Cadmium	0 (1973)	6 (1970)	----
Calcium (ppm)	4.7-7	6.2-7.1	6.2 (1973)
Cobalt	<1 (1973)	4 (1970)	----
Chromium (Cr^{+6})	7 (1973)	0 (1970)	----
Copper	12 (1973)	23 (1966)	----
Iron	320-550	50-256	260 (1973)
Lead	<.5 (1972) 5 (1973)	12 (1970) 50 (1966)	----
Manganese (ppm)	.76-1.1	1.1-1.3	1.1 (1973)
Mercury	----	4.7 (1970)	----
Molybdenum	0 (1973)	----	----
Nickel	4 (1973)	6.6 (1966)	----
Potassium (ppm)	.8-1.5	1.12-1.35	1.2 (1973)
Selenium	----	----	----

Continued

TABLE 30. Continued

METAL	ABOVE LOWELL	BELOW CONCORD RIVER AT LOWELL	WEST NEWBURYPORT
Silver	0 (1973)	----	----
Sodium (ppm)	11.1-12	10.1-13.3	10.7 (1973)
Tin	<1 (1973)	----	----
Vanadium	<0.8 (1973)	----	----
Zinc	10 (1973)	4 (1970) 73 (1966)	----

[1] Values are in ppb unless otherwise specified

Data for major cations, calcium, iron, potassium, and sodium, are more complete and ranges are presented.

Above Lowell (1972-1973)

Below Concord River (1966-1971) at Lowell.

arsenic	0 ppb
cadmium	1 ppb
chromium	0 ppb
cobalt	1 ppb
lead	4 ppb
mercury	<.5 ppb
zinc	20 ppb

The Squannacook River had concentrations of 0.11 ppm iron, and 0.04 ppm manganese in April of 1973.

In summary no significant changes in water quality (all parameters) were evident in the streams under consideration, from 1964 to the present. As will be made clear in later sections, the streams in the Merrimack River Basin are suffering from an intensive loading of domestic and industrial wastes. This has resulted in elevated nutrient levels, decreased levels of dissolved oxygen, and elevated concentrations of toxic materials. The direct consequence of this waste loading has been the degradation of biologic communities in the Merrimack River Basin.

5. Sediments

The importance of the physical and chemical characteristics of instream sediments to the aquatic biosphere is well documented. Fish and invertebrates are known to require specific sediment types for egg deposition, feeding, and habitat. Although little data are available relevant to toxic concentrations of particular metals and other materials in interstitial waters, it is known that benthic organisms in marine environments biomagnify trace metals differentially according to their feeding habits (Normandeau Associates, Inc., 1972), and there is no reason to believe that this process does not also occur in freshwater environments.

a) PHYSICAL CHARACTERISTICS

The general substrate type observed in the Merrimack River and its tributary streams was composed primarily of fine to coarse sand containing variable amounts of organic material. This sandy substrate was overlain by a thin layer of flocculant organic material, approximately 0.5 cm in thickness. Sites sampled on the Sudbury, Concord and Powwow Rivers had much thicker layers of flocculant and semi-consolidated organic material derived from extensive marsh areas on these rivers. Table 31 contains data on the

TABLE 31. EROSION POTENTIAL OF SAMPLED MERRIMACK RIVER BASIN SEDIMENTS

MAXIMUM PERMISSIBLE VELOCITIES ALONG THE WETTED PERIMETER IN CM/SEC. [1]

SITE	CLEAR WATER		WATER CARRYING FINE SILT		WATER CARRYING SAND AND GRAVEL	
	$\bar{X}$	$\bar{R}$	$\bar{X}$	$\bar{R}$	$\bar{X}$	$\bar{R}$
5, Merrimack River at Lowell	49.2	45-60	79.2	75-90	52.2	45-81
4, Merrimack River at Lawrence	46.2	45-51	76.2	75-81	45.0	---
3, Merrimack River at Haverhill	51.0	30-75	85.2	75-111	61.2	30-96
8, Concord River at Billerica	---[2]	---[2]	---[2]	---[2]	---[2]	---[2]
6, Squannacook River at Townsend	45.0	30-60	75.0	75-90	45.0	30-60

[1] 30 cm/sec = 1 fps

[2] samples could not be analyzed using presently available techniques. These samples were highly organic and have a true specific gravity of 1.1. Erodible velocities estimated to be in the range of 15 to 30 cm/sec.

erosion potential of the sampled sediments. Sediments from the Merrimack and Squannacook Rivers are essentially similar, while those of the Concord River are very easily eroded by slight current stress. The critical velocities for erosion in all of the rivers studied are expected to be equaled or exceeded during periods of spring runoff. Data on degree of saturation and volatile solids are presented in Table 32. Again the Merrimack and Squannacook River sediments are generally comparable, while the Concord River deposits show a high degree of saturation and organic content, as do those collected from the Sudbury River. There appears to be a trend toward increasing volatile solids content proceeding downstream from Lowell to Haverhill in the Merrimack River.

b) CHEMICAL CHARACTERISTICS

Table 33 contains data on the amount of total solids, volatile solids, biochemical oxygen demand, organic nitrogen, total phosphorous, total trace metals, and available trace metals.[1] Biochemical oxygen demand, organic nitrogen, and total phosphorous appear to be generally correlated with volatile solids as expected. The metals: zinc, lead, mercury, copper, nickel, and aluminum were detected in all samples, while chromium was found in all but two core samples. Cadmium was found in only one core sample, while boron was never detected (the threshold of detection of 1000 ppm for boron probably explains this). Inspection of Table 34 reveals a general increase in the combined trace metal content of Merrimack River sediments proceeding downstream. This trend is probably dependent upon continued discharge of metals from industrial and domestic sources, and the larger amounts of available organic binding materials present in the downstream sediments. The deposit at Site 8 on the Concord River at Billerica contained the largest trace metal load while Site 6 on the Squannacook at Townsend contained the least amount. Definite downstream concentration increases in the Merrimack River were observed for zinc, chromium, and copper, indicating that these metals are generally discharged. Lead, mercury, nickel, and aluminum were observed to generally increase proceeding downstream in the Merrimack River but did not present distinct trends, indicating a more spotty input of these metals.

[1] Analytical procedures by U. S. Army Corps of Engineers Water Quality Laboratory, Barre Falls, Mass.

TABLE 32. DEGREE OF SATURATION AND VOLATILE SOLIDS CONTENT OF SAMPLED SEDIMENTS

SITE	TOTAL SOLIDS[1] %		WATER CONTENT %		VOLATILE SOLIDS % DRY WT	
	$\bar{X}$[2]	R[3]	$\bar{X}$	R	$\bar{X}$	R
3	76.77	71.14-79.41	23.23	28.86-20.59	1.84	0.79-2.91
4	71.12	64.51-73.66	28.88	35.49-26.34	1.37	0.47-2.65
5	76.52	75.10-78.52	23.48	24.90-21.48	0.99	0.32-2.35
6	78.45	73.55-81.79	21.55	26.45-18.21	0.66	0.17-1.36
8	21.05	13.06-27.45	78.95	86.94-72.55	26.58	22.67-32.11
11	49.54	42.29-56.70	50.46	57.71-43.30	N.T.	---

[1] After Decantation of free water

[2] Mean

[3] Range

N.T. = Not Tested

TABLE 33. PHYSICAL AND CHEMICAL CHARACTERISTICS OF SEDIMENTS FROM SELECTED SITES IN THE MASSACHUSETTS SECTION OF THE MERRIMACK RIVER BASIN[1]

SITE	MERRIMACK AT HAVERHILL		MERRIMACK AT LAWRENCE		MERRIMACK AT LOWELL		SQUANNACOOK AT TOWNSEND		CONCORD AT BILLERICA		SUDBURY AT FRAMINGHAM		DETECTION LIMIT (ppm)
CLEAN WATER	3		4		5		6		8		11		
	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	
Max. Permissible Velocity FPS (Clear Water)	1.7	1.0-2.5	1.54	1.5-1.7	1.6	1.5-2.0	1.5	1.0-2.0	0.5	1.0[2]	--	--	
Total Solids %	76.77	71.14-79.14	71.12	64.51-73.66	76.52	75.10-78.52	78.45	73.55-81.79	21.05	13.06-27.45	49.54	42.29-56.70	
Volatile Solids %	1.84	0.79-2.91	1.37	0.47-2.65	0.99	0.32-2.35	0.66	.17-1.36	26.58	22.67-32.11	--	--	
BOD mg O_2/kg	168	70-280	236	100-400	78	50-160	76	30-150	1006	810-1190	--	--	
Organic N (ppm)	252	<3.8-450	909	333-1890	340	160-822	209	<3.2-520	7300	5400-8250	2943	2620-3430	
Total P (ppm)	.177	.0952-.316	.265	.140-.648	.151	.0729-.330	.104	.0275-.182	1.36	0.544-2.79	.277	.254-.317	
Total Lead (ppm)	21.7	0-41.5	37.62	27.7-62.0	14.6	12.0-19.0	14.4	12.0-20.0	283.2	171-453	175.2	78.7-259.0	8.0
Available Lead	N.D.	--	N.D.	--	N.D.	--	N.D.	--	N.D.	--	N.D.	--	
% Available	--	--	--	--	--	--	--	--	--	--	--	--	
Total Zinc	82.7	59.1-141.0	70.26	42.7-106.0	39.58	34.7-40.8	18.3	6.2-33.5	191.8	189-199	190	189-191	0.8
Available Zinc	4.58	0.8-11.9	3.68	2.5-5.0	4.44	1.4-5.9	2.12	1.3-3.0	12.36	8.0-18.6	14.57	13.5-16.3	
% Available	5.54	1.2-14.0	5.24	3.3-12.0	11.22	3.7-15.0	15.74	8.4-26.0	6.44	5.2-9.7	7.7	7.1-8.6	
Total Mercury	136.6	81-188	33.16	16.0-47.0	61.3	32.5-90.0	77.8	31-123	25.04	0.0-49.5	18.9	12.8-27.0	1.0
Available Mercury	--	--	--	--	--	--	--	--	--	--	--	--	
% Available	--	--	--	--	--	--	--	--	--	--	--	--	
Total Cadmium	N.D.	--	N.D.	--	N.D.	--	N.D.	--	1.2	--	N.D.	--	0.8
Available Cadmium	--	--	--	--	--	--	--	--	N.D.	--	--	--	
% Available	--	--	--	--	--	--	--	--	--	--	--	--	

TABLE 33. (Continued)

SITE CLEAN WATER	MERRIMACK AT HAVERHILL 3		MERRIMACK AT LAWRENCE 4		MERRIMACK AT LOWELL 5		SQUANNACOOK AT TOWNSEND 6		CONCORD AT BILLERICA 8		SUDBURY AT FRAMINGHAM 11		DETECTION LIMIT (ppm)
	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	$\bar{X}$	R	
Total Chromium	234.9	31.7-459	164.08	83.3-395.0	148.72	118.0-221.0	79.74	0-111	568	224-1000	39.57	16.0-78.7	8.0
Available Chromium	N.D.	--	N.D.	--	N.D.	--	--	--	N.D.	--	N.D.	--	
% Available	--	--	--	--	--	--	--	--	--	--	--	--	
Total Copper	40.18	16-66.4	28.34	10.0-35.3	14.94	6.1-30.7	14.94	2.3-38.2	108.38	91.3-150.0	86.3	62.7-103	1.6
Available Copper	N.D.	--	0.58	0.3-1.0	1.04	.7-1.3	N.D.	--	N.D.	--	0.4	--	
% Available	--	--	2.05	1.1-4.0	6.96	4.2-15.0	--	--	--	--	0.4	--	
Total Nickel	87.58	35.6-144	55.96	44.2-71.9	82.88	51.6-114.0	63.9	21.5-80.2	57.78	51.8-68.5	32.6	16.0-46.5	1.6
Available Nickel	N.D.	--	N.D.	--	3.07	2.0-5.0	N.D.	--	N.D.	--	1.1	0.6-1.6	
% Available	--	--	--	--	2.22	3.0-4.8	--	--	--	--	5.65	10.0-113	
Total Aluminum	48.48	36.9-67.2	50.08	32.0-70.2	28.72	23.0-35.9	19.9	10.0-41.7	127.4	108.0-178.0	70.37	66.1-77.5	0.4
Available Aluminum	N.D.	--	N.D.	--	N.D.	--	--	--	N.D.	--	N.D.	--	
% Available	--	--	--	--	--	--	--	--	--	--	--	--	
Total Boron	N.D.	--	N.D.	--	N.D.	--	N.D.	--	N.D.	--	N.D.	--	1000
Available Boron	--	--	--	--	--	--	--	--	--	--	--	--	
% Available	--	--	--	--	--	--	--	--	--	--	--	--	

[1]values in ppm unless otherwise indicated

[2]estimate

TABLE 34. TOTAL TRACE METALS IN SEDIMENTS SAMPLED

SITE	RIVER	TOTAL TRACE METALS (ppm)
3-Haverhill	Merrimack	652.14
4-Lawrence	Merrimack	439.50
5-Lowell	Merrimack	390.74
6-Townsend	Squannacook	288.98
8-Billerica	Concord	1470.80
11-Framingham	Sudbury	612.94

To serve as a comparative base, data collected from the heavily contaminated Nashua River sediments at Leominster in 1971 is presented in Table 35.

TABLE 35. TRACE METALS IN NASHUA RIVER SEDIMENTS AT LEOMINSTER (1971) COLLECTED BY THE MASSACHUSETTS DIVISION OF WATER POLLUTION CONTROL AND ANALYZED BY THE DEPARTMENT OF PUBLIC HEALTH

(from Lyman, Noyes, and Heeley, in Press)

METAL	CONCENTRATION (ppm) (DRY WEIGHT BASIS)
Lead	820.0
Zinc	580.0
Mercury	5.6
Cadmium	260.0
Chromium	260.0
Copper	350.0
Nickel	82.0
Total Metals	2357.6

Comparison of these results to those for the stream sampled by Normandeau Associates, Inc. in 1973 shows that the Concord River sediments at Billerica are not similar to the Nashua River sediments in metal content. Nickel concentrations are generally comparable, while lead, zinc, cadmium, chromium and copper occur in generally higher concentration in the Nashua River. Mercury levels are quite interesting in that the Nashua River sediments contain much less than the sediments collected from the Sudbury, Concord, Squannacook, and Merrimack Rivers.

Tests showed that zinc contained in the sediments sampled could readily be exchanged with overlying water, and that the degree of availability was apparently related to the amount of contained organic matter. Copper and nickel were also shown to be available to the overlying water but not as readily as zinc. All other metals appeared to be strongly bound to the sediments.

Although little is known concerning the direct toxic effects of sediment metal content, it is clear that the metals are in a position to be biomagnified by rooted aquatic macrophytes, some benthic invertebrates, and fish utilizing these organisms as a food source. Historical data on pesticide contamination of Merrimack River Basin sediments have been spotty. The only data pertaining to the soft silt-clay sediments of the Estuary were reported by Jerome *et al.* (1965). These workers found that DDT was concentrated in the Merrimack River Estuary sediment. Their results (shown in Table 36) indicate that DDT was more heavily concentrated on the Salisbury side of the estuary than on the Newburyport side.

TABLE 36. PESTICIDE CONCENTRATIONS IN MUD SAMPLES TAKEN AT NEWBURYPORT AND SALISBURY, MERRIMACK RIVER ESTUARY, 1964.

(from Jerome *et al.*, 1964)

DATE COLLECTED	SITE	HEPTACHLOR EPOXIDE (ppm DRY WEIGHT)	DIELDRIN OR DDE (ppm DRY WEIGHT)	DDT (ppm DRY WEIGHT)
June 17	Newburyport	No Test	None	2.400
June 17	Salisbury	No Test	None	4.100
July 10	Newburyport	None	None	2.600
July 10	Salisbury	None	None	5.300

Data from Collier, *et al.*, (1972) on trace metals in Merrimack River Estuary sediments analyzed by neutron activation indicated that chromium levels in the estuarine sediment were not substantially different from those found in the Merrimack River. The observed chromium levels ranged from 89.4 ppm to 105 ppm.

Data previously presented on the observed concentrations of certain metals in Merrimack River water samples are too spotty to compare with levels of these metals observed in the sediments.

6. Biological Communities

Perhaps best said by MacKenthun and Ingram (1967):

> "Organisms respond to the aquatic environment by producing an aquatic crop that is suited best for the particular environment in which they exist. Organisms also respond to changes that may take place within their environment with shifts in species dominance in the aquatic community and with sometimes dramatic changes in the population numbers of a single species or a group of species with similar habitat requirements. Because of this response of the biota to the aquatic environment, biology has an important role in the characterization of water quality and the interpretation of population trends within the biota."

Responses of the kind suggested by MacKenthun and Ingram are evident in the Merrimack River watershed. They are evident in the plankton communities; they are evident in the aquatic macrophyte communities; they are evident in the benthic invertebrate communities; and they are evident in the fish communities. While no real, pristine, areas were encountered in the fall, 1973, field study, enough contrasts were available to illustrate the effects of man's influence on the natural environment in Northeast Massachusetts.

a) PLANKTON

Planktonic algae are one of the most important components of the aquatic ecosystem, since they, along with the aquatic macrophytes, are the primary producers of organic materials essential for life. The response of these simple, relatively primitive organisms to abiotic environmental charges is extremely rapid, often observable as blooms, floating scums, or floating mats of filamentous forms. It is easier, however, to demonstrate a relationship between algal population responses and environmental disturbance in standing waters, or the slower moving portions of larger streams, than in fast flowing streams. In a flowing stream, water passes quickly from point to point; algae collected in a particular water sample would have been environmentally influenced at some distance upstream. In the words of MacKenthun and Ingram (1967), "In some instances the reach of stream studied may be too short to apply a meaningful interpretation."

The Merrimack River and its tributaries are characterized by running waters which are often interrupted by standing, impounded waters. Also, near the mouth of the Merrimack River, there is a zone of transition where freshwater communities intermix with estuarine communities for over a half dozen miles, producing a mixed assemblage of organisms.

The general composition of planktonic communities in the Merrimack River watershed is shown in Figure 16. Additional details, particularly as they relate to the "miscellaneous" category of Figure 16, are given in Table 37, which also includes notations of dominant forms. From these data we can see that the Merrimack River system is typically dominated by diatoms, principally *Melosira,* however blue-green algae (Cyanophyta) are also abundant in the highly "enriched" SUASCO system (Stations 8, 9, 10, 11, 1B).

Diatoms are typically the dominant plankton group in stream systems (Hynes, 1970). Generally speaking, they are not the causative agent of aquatic problems, but in some cases they may clog water supply filter systems and cause taste problems when present in high abundances (MacKenthun and Ingram, 1967).

Blue-green algae are most often implicated in "nuisance" situations. Blooms of their genera are frequently associated with high concentrations of nutrients (nitrogen, phosphorous, carbon). These blooms have historically been responsible for fish-kills through deoxygentation of waters and, in mammalian illnesses (gastroenteritis and low milk yield). In addition, they can cause taste, odor, and aesthetic problems. Genera which have been implicated in animal deaths include: *Microcysts, Aphanizomenon, Anabaena, Nodularia, Coelosphaerium,* and *Gleotrichia. Aphanizomenon* and *Anabaena* were dominant in some of the samples collected during the fall 1973 studies. Although no known incidences of death or illness in the area have been attributed to blue-green algae, they are highly suspect of causing localized odor problems.

Detailed information on numerical abundances of plankton groups present in the tributaries of the Merrimack during fall, 1973, are given in Table 38. The pattern of blue-green dominance in the SUASCO system is evident, especially in the Concord River (Stations 8 and 9). It is also apparent that total phytoplankton numbers are reduced in the relatively

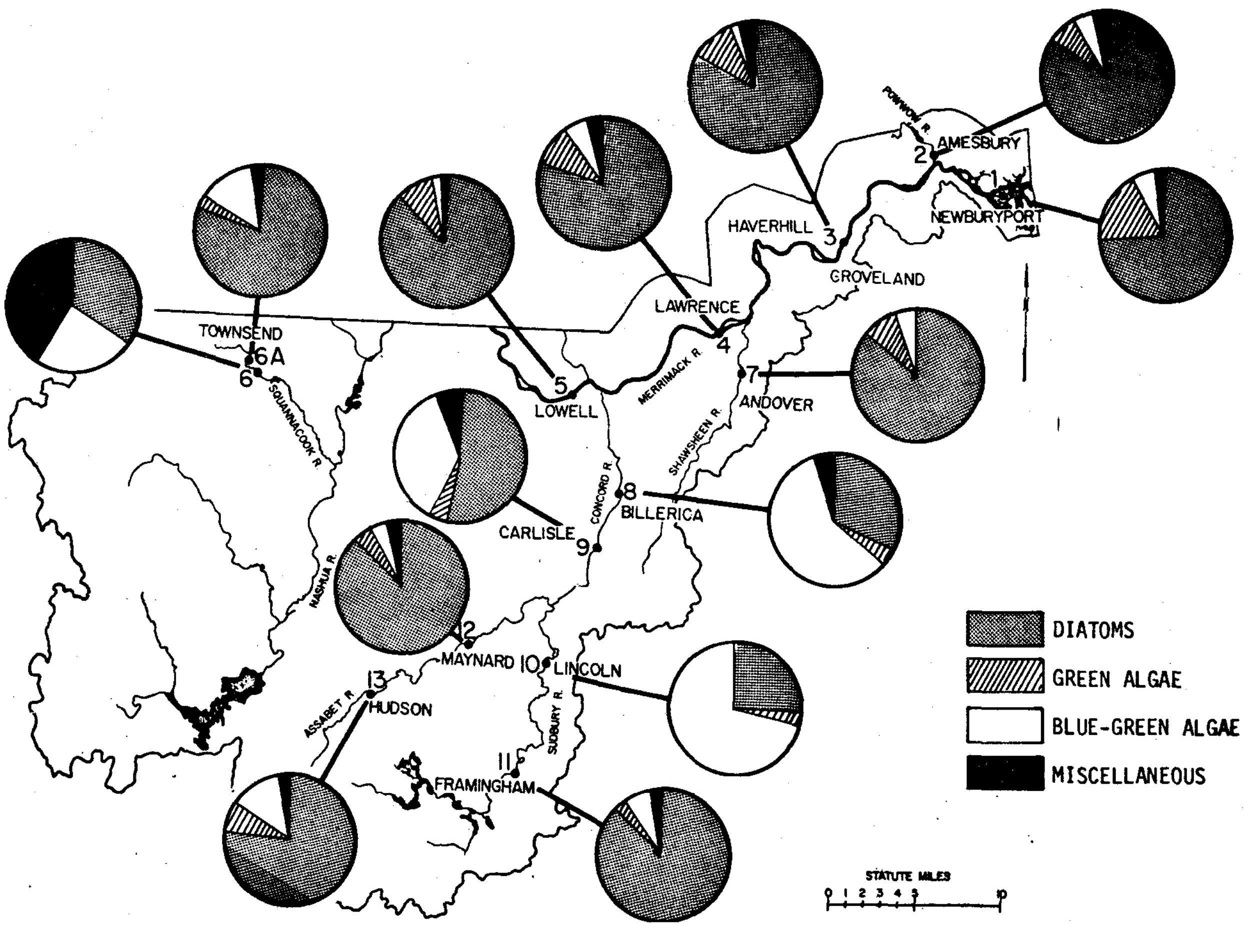


Figure 16. Relative abundance of major planktonic groups in Merrimack River Basin, September - October, 1973.

TABLE 37. PERCENTAGE COMPOSITION OF MAJOR PLANKTON TAXA IN SAMPLES TAKEN IN THE MERRIMACK RIVER WATERSHED, SEPTEMBER - OCTOBER, 1973

STATION	DIATOMS (CHRYSOPHYTA)	GREEN ALGAE (CHLOROPHYTA)	BLUE-GREEN ALGAE (CYANOPHYTA)	ZOOPLANKTON	YELLOW-BROWN ALGAE (CHRYSOPHYTA)	RED ALGAE (RHODOPHYTA)	EUGLENA (EUGLENOPHYTA)	DOMINANT GENERA
1	73.85	18.2	4.1	2.55	1.3	----	----	*Melosira*
2	84.7	6.9	5.55	2.55	0.3	----	----	*Melosira*, *Pediastrum*, Rotifers
3	83.05	9.6	1.75	4.75	0.85	----	----	*Melosira*, *Asterionella*, *Scenedesmus*, Rotifers
4	78.3	10.2	7.8	2.6	1.1	----	----	*Melosira*, *Scenedesmus*, *Pediastrum*, *Ciliophoruns*, Rotifers, *Aphanizomenon*, *Anacystis*, *Anabaena*, *Mallomonas*
5	86.0	8.6	1.75	2.6	1.05	----	----	*Melosira*, *Asterionella*
6	33.25	---	25.0	---	41.75	----	----	----
6A	80.0	1.75	16.95	1.3	---	----	----	*Cymbella*
7	87.4	10.25	2.35	---	---	----	----	----
8	33.55	2.3	62.1	0.45	1.5	----	0.1	*Melosira*, *Scenedesmus*, *Aphanizomenon*, *Anacystis*, *Anabaena*
9	52.3	4.5	41.2	0.35	1.5	0.05	0.1	*Melosira*, *Asterionella*, *Scenedesmus*, *Aphanizomenon*, *Anacystis*, *Mallomonas*, *Anabaena*, *Microspora*
10	26.4	1.9	71.7	---	---	---	---	*Aphanizomenon*

Continued

TABLE 37. (Continued)

STATION	DIATOMS (CHRYSOPHYTA)	GREEN ALGAE (CHLOROPHYTA)	BLUE-GREEN ALGAE (CYANOPHYTA)	ZOOPLANKTON	YELLOW-BROWN ALGAE (CHRYSOPHYTA)	RED ALGAE (RHODOPHYTA)	EUGLENA (EUGLENOPHYTA)	DOMINANT GENERA
11	86.1	1.35	9.65	1.95	0.95	----	----	*Asterionella, Aphanizomenon, Melosira*
12	86.9	5.3	4.4	1.7	1.7	----	----	Assorted Pennates
13	77.0	8.55	12.85	0.85	0.75	----	----	*Synedra*

TABLE 38. MEAN ABUNDANCE OF PLANKTONIC ORGANISMS TAKEN (THOUSANDS/100 l) MERRIMACK RIVER TRIBUTARIES SEPTEMBER - OCTOBER 1973

STATION*	DIATOMS	GREEN ALGAE	BLUE-GREEN ALGAE	ZOOPLANKTON	YELLOW-BROWN ALGAE
2	2594.1	203.0	183.5	75.3	12.4
6	4.4	0	1.8	0	4.0
6A	257.3	4.4	54.3	4.9	0
7	38.4	7.4	1.7	0	0
8	3020.9	206.3	5174.0	40.4	0
9	6974.6	619.4	5453.3	46.5	0
10	138.7	10.0	376.5	0	0
11	1179.0	18.5	124.0	25.6	0
12	369.5	22.2	18.5	7.4	0
13	427.3	47.5	71.4	4.5	0

* see Figure

smaller and less polluted rivers, the Squannacook (Stations 6 and 6A) and the Shawsheen (Station 7). Figure 17 illustrates individual station abundances as a percentage of total numbers of plankton sampled over all stations. Twelve of the fourteen stations sampled, accounted for about fifty percent of the total plankton counted, while the two Concord River stations (8 and 9) alone, comprised the remaining fifty percent.

Numerical abundance of plankton groups collected in the Merrimack River (Stations 3, 4, and 5) during fall 1973 is given in Table 39.

TABLE 39. AVERAGE COMPOSITION OF REPLICATE SAMPLES TAKEN IN THE MERRIMACK RIVER IN SEPTEMBER - OCTOBER, 1973 (IN THOUSANDS/100L)

STA	DIATOMS	GREEN ALGAE	BLUE-GREEN ALGAE	ZOOPLANKTON	YELLOW-BROWN ALGAE	RED ALGAE	EUGLENA
3	688.9	98.4	22.7	45.4	---	---	---
4	2534.6	342.2	264.0	87.9	34.2	---	---
5	303.6	35.0	3.5	19.3	7.6	---	---

While the percentage of blue-green algae are not as high in the Merrimack mainstem as in the SUASCO system (1.8 to 7.8 percent compared to 41.2 to 62.1 percent), the overall abundance of phytoplankton is very high, probably reflecting nutrient enrichment. A relationship between high phytoplankton numbers and nutrient enrichment is supported by comparison with Hooksett Pond, an upstream environment similar to the lower mainstem in many respects, except that nutrient loading is less. Hooksett Pond, located near Concord, New Hampshire is a small impoundment of the Merrimack River. During the same period (fall, 1973) the Merrimack mainstem stations in Massachusetts (at Lowell, Lawrence and Haverhill) exhibited substantially greater plankton abundance (cf. Tables 39 and 40).

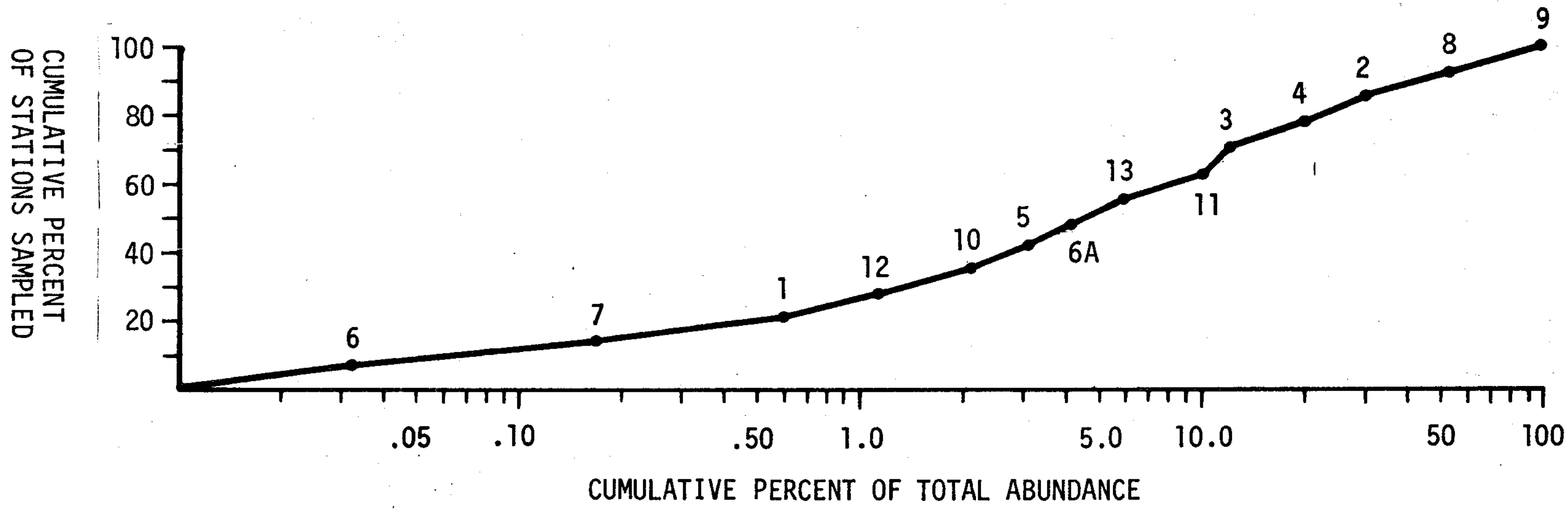


Figure 17. Log cumulative percent of total abundance* vs. cumulative percent of stations.

*Total abundance equals the sum of all organisms sampled during the study at all stations.

TABLE 40. COMPOSITION OF PLANKTON SAMPLES TAKEN IN SEPTEMBER - OCTOBER, 1973, IN HOOKSETT POND, NEW HAMPSHIRE (IN THOUSANDS/100 L) (NORMANDEAU ASSOCIATES, INC., IN PREPARATION)

DATE	DIATOMS	GREEN ALGAE	BLUE-GREEN ALGAE	ZOOPLANKTON	YELLOW-BROWN ALGAE	RED ALGAE
9/25/73	71.8	76.6	1.0	8.3	2.8	0.3
10/1/73	112.7	50.7	3.8	4.1	4.1	0.3
10/10/73	774.6	137.8	5.4	14.2	29.7	4.0

Zooplankton in the Merrimack River basin during fall, 1973, were most abundant at Lawrence (Station 4) and Haverhill (Station 3) in the mainstem, and in the Powwow and Concord River tributaries. The community was characterized by rotifers and ciliophoran protozoans, both of which are indicative of high organic loading (Hynes, 1970).

In the Merrimack River Estuary, both spatial and temporal patterns in plankton distribution occur (Normandeau Associates, Inc., 1971). Twenty-two species, five genera, and at least seven higher phytoplankton taxa were identified from 1971 spring samples. The phytoplankton was comprised chiefly of diatoms, although dinoflagellates and green algae were also present. All major phyla were represented in the zooplankton, with calanoid copepods being the most abundant zooplankter. Sampling diversity was greatest in the seaward portion of the estuary and gradually decreased upriver. Typical marine-estuarine assemblages were found near the seaward section of the estuary, and in near-bottom tows throughout the estuary. The dominant marine-estuarine forms were the estuarine diatoms *Chaetoceros debilis, Thalassiosira gravida,* and *Thallassiothrix nitzschioides*. Freshwater forms such as *Vorticella* and *Keratella cochlearis* were found in the upper estuary, primarily in surface tows.

In the fall, of 1971, thirty-three species, four genera, and at least nine higher taxa were present in the estuary. The phytoplankton was composed of approximately equal numbers of diatom and dinoflagellate species, plus two chlorophytes (greens) and one cyanophyte (blue-green). Species which are abundant in the spring plankton were no longer present. Most major phyla of zooplankton were represented. The calanoid copepod group contained the largest number of species, while rotifers and bottom invertebrates were also abundant. Diversity was greatest in the seaward section of the estuary, and decreased gradually upriver. At the seaward station the planktonic community was composed primarily of marine-estuarine forms dominated by species of dinoflagellates, bivalve larvae, and copepods. Upriver assemblages were primarily composed of freshwater forms such as *Fragillaria crotonensis, Thalassiothrix fraunfeldii, Pediastrum bivae,* and *Staurastrum clorsidentiferum,* all of which were present in "bloom" abundance. Data collected on the plankton population in the Merrimack River Estuary during fall, 1973, are presented in Table 41.

TABLE 41. PLANKTON POPULATION
IN THE MERRIMACK RIVER ESTUARY
OBSERVED DURING
SEPTEMBER - OCTOBER, 1973 SURVEY
(in thousands/100 L)

DIATOMS	GREEN ALGAE	BLUE-GREEN ALGAE	ZOOPLANKTON	YELLOW-BROWN ALGAE
155.7	25.9	5.2	10.4	5.2

The overall composition of plankton in the Merrimack River Estuary is typical of estuaries where resident populations of marine and estuarine forms are maintained as a result of incomplete flushing. This contrasts with estuaries which have complete flushing. These estuaries contain a freshwater plankton community during the ebbing tide (river derived), and a marine assemblage during the flooding tide (offshore derived).

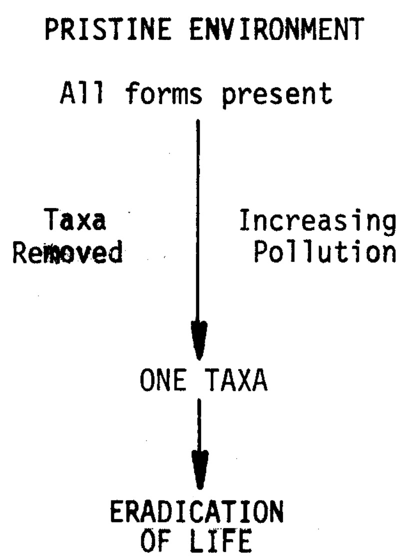
b) BENTHIC INVERTEBRATES

Benthic organisms are animals that live in direct association with the bottom substrate. They may be found crawling or walking on the bottom (motile epifauna), burrowing in the bottom (infauna) or attached to the bottom (sessile epifauna). The organisms considered in this study are the benthic macrofauna, which are operationally defined as those organisms which are retained on a No. 30 (590 micron) seive. Essentially, this fraction contains all organisms which may easily be seen with the naked eye.

The benthic community is composed of a variety of taxa which are differentially affected by environmental (natural and man-induced) stress. In addition, many of these organisms have both a relatively sessile life mode and a sufficiently long life cycle, so that they cannot readily avoid deleterious water quality conditions.

As an initially pristine river or stream begins to become polluted, the benthic community structure becomes altered. With moderate pollution, the most sensitive organisms are eliminated. As the pollution load is increased, animal types are removed in order of their pollution sensitivity until only the most tolerant forms remain. A large pollution load, that is one containing many toxins and little nutrients, may eradicate all bottom life, thus depriving higher organisms (e.g., fish) of an important food source.

As more sensitive forms are eliminated, ecologic pressures such as food, space and predation become less limiting for the more tolerant forms, and they increase in abundance until available food and space become limiting.



This pattern may occur in one place over time or over an area downstream from a source of pollution.

Figure 18 shows representative bottom dwelling macrofauna grouped by their tolerances. Of course, flexibility must be maintained in establishing tolerance lists because of complex physical, chemical, and biologic interactions. However, some general tolerance patterns may be established. Stonefly nymphs, mayfly naiads, hellgrammites, and caddisfly larvae are organisms that are highly sensitive to environment changes. Black fly larvae, scuds, sowbugs, snails, fingernail clams, dragonfly nymphs, and most midge larvae

Legend to Figure 18.

A. Stonefly nymph (Plecoptera)

B. Mayfly naiad (Ephemeroptera)

C. Hellgrammite or Dobsonfly larvae (Corydolidae)

D. Caddisfly larvae (Trichoptera)

E. Black fly larvae (Simuliidae)

F. Scud (Amphipoda)

G. Aquatic sowbug (Isopoda)

H. Snail (Gastropoda)

I. Fingernail Clam (Sphaeridae)

J. Damselfly nymph (Zygoptera)

K. Dragonfly nymph (Anisoptera)

L. Bloodworm or midge fly larvae (Tendipedidae)

M. Leech (Hirundinea)

N. Sludgeworm (Tubificidae)

O. Sewage fly larvae (Psychoda)

P. Rat-tailed maggot (Tubifera-Eristalis)

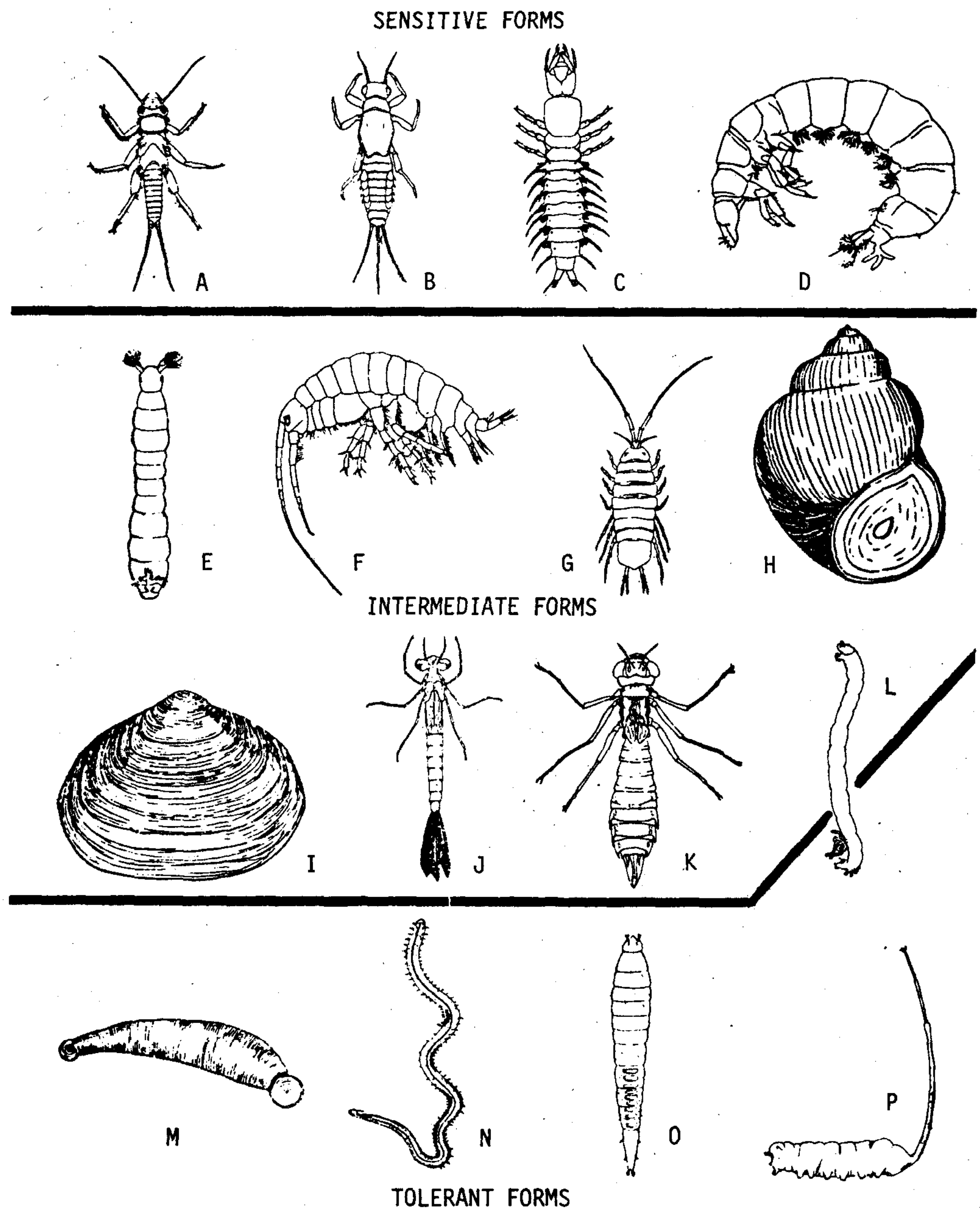


Figure 18. Pictorial arrangement of benthic organisms based on their relative sensitivities to environmental stress.

are intermediate in tolerance. Sludgeworms, some types of midge larvae (bloodworms), and some leeches are tolerant of heavy organic pollution loads. Sewage mosquitoes *(Culex)* and rat-tailed maggots *(Eristalis)* are tolerant of anaerobic conditions.

Oldaker's (1966) results for the Merrimack River are given in Figures 19 and 20. Figure 19 indicates the distribution and abundance of sensitive, intermediate, and tolerant forms. No clean water assemblage (stoneflies, mayflies, caddisflies, etc.) was found in the Merrimack River. From the headwaters of the Merrimack River to Manchester, New Hampshire, the bottom community was characterized by moderate species abundances and high species diversity (Figures 19 and 20). It was composed of organisms with intermediate pollutional tolerance. Below Manchester, there was an abrupt decrease in species diversity. From this point to the estuary, tolerant forms, i.e. sludgeworms (Tubificidae) and bloodworms (Tendipedidae) dominated the benthos. Their abundance fluctuated cyclically, being depressed drastically upon entering a population center, then increasing until the next population center was reached. The very high organic loads and/or substantial amounts of toxic materials present in the river below population centers, also caused marked reductions in the abundance of even the most tolerant benthic organisms.

Data from 1964-1965 (Oldaker, 1966), 1971 (Normandeau Associates, Inc., 1971) and 1973 (Normandeau Associates, Inc., in preparation), for the Merrimack River Estuary, show an impoverished, low diversity benthic fauna. Only a few pollution tolerant species are found. This condition is probably caused by a combination of natural and man-induced factors. The community is physically stressed by turbulence and scouring action of strong tidal currents. These strong currents leave a substrate of mixed pebble and gravel in the main channel area which is not well suited for benthic organisms. The estuary is also stressed by massive salinity changes as well as a heavy load of domestic and industrial pollutants. Even though the benthic fauna would be of low diversity as a result of natural conditions, the addition of pollutants has further degraded the community.

In the estuary, historically, the soft shell clam *(Mya arenaria)*, fishery has been an important commercial resource. The edible blue mussel *(Mytilus edulis)* also occurs in the estuary, but is not utilized. At present, the extensive mud flats at the north and south sides of the estuary constitute an excellent habitat for soft shell clams. These have been little disturbed by dredging and filling operations (Jerome *et al.*, 1965). Although it

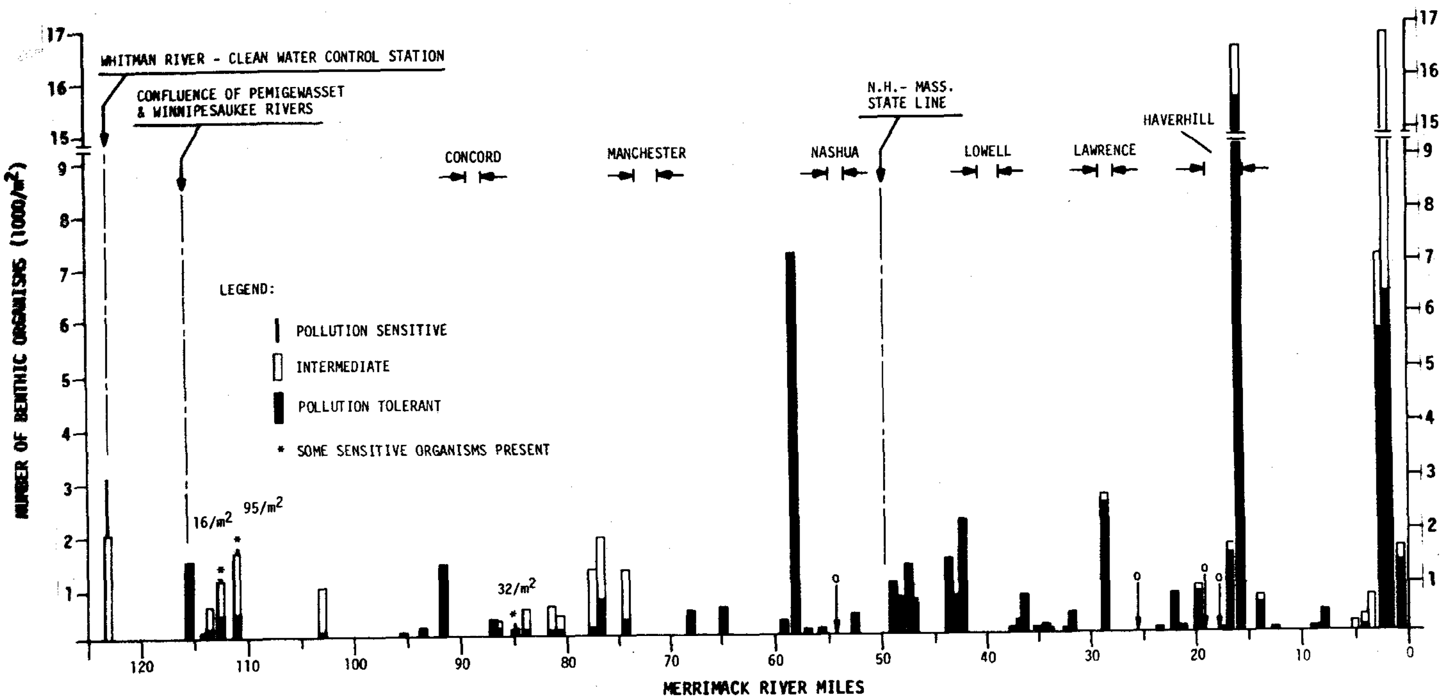


Figure 19. Abundance and tolerance groupings of benthic organisms in Merrimack River 1964 - 1965 (adapted from Oldaker, 1966).

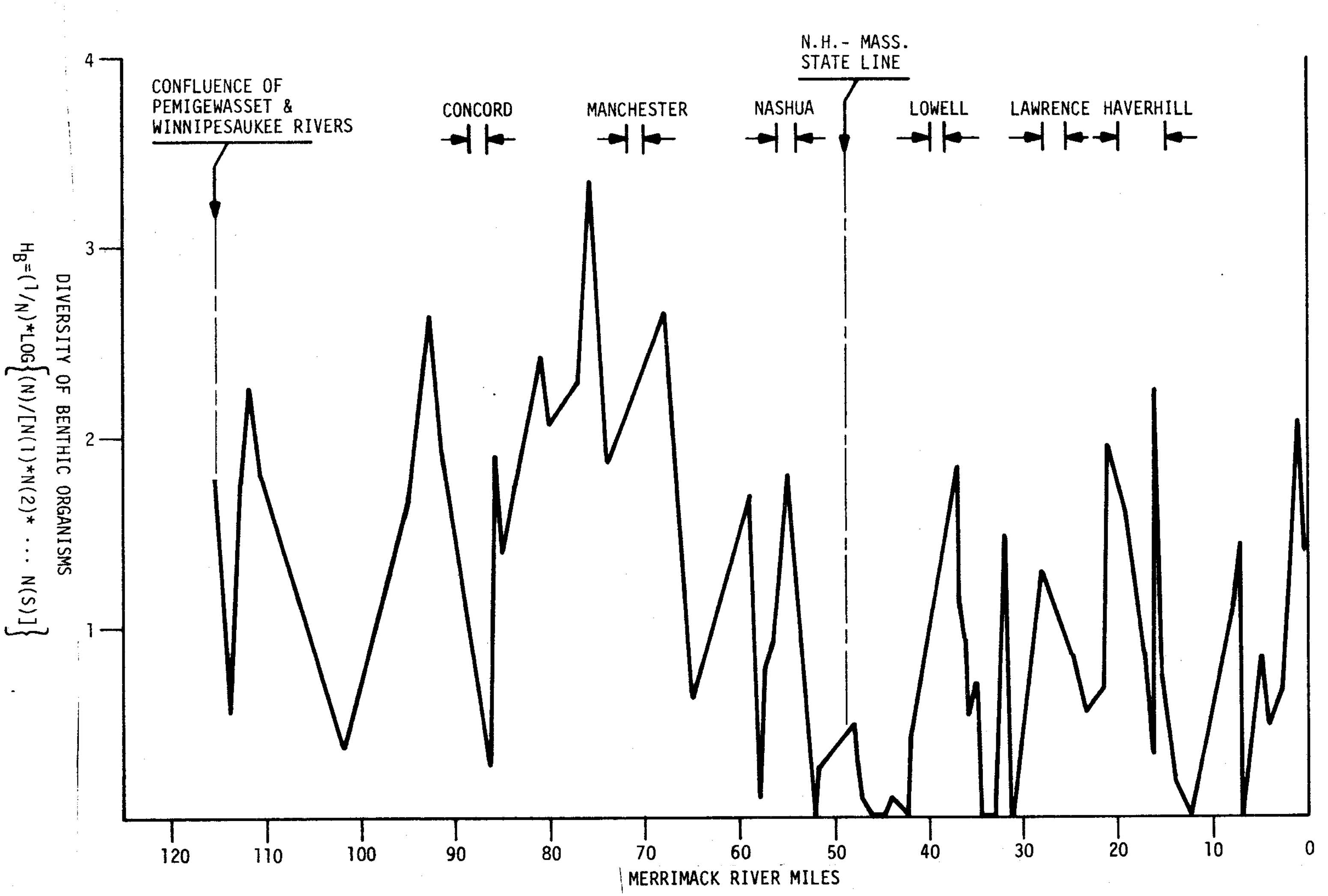


Figure 20. Species diversity of benthic organisms in the Merrimack River, 1964-65 (calculated from data presented in Oldaker, 1966).

appears that pollution has had little or no direct affect on the soft shell clam population's viability it has had a tremendous impact on human utilization of this resource.

Soft-shelled clams were examined in 1964 for the presence of pesticides (Table 42). Heptachlor, DDT, Dieldrin, or DDE, were present in at least two of the ten specimens collected at each site. Heptachlor Epoxide was recorded in quantities of 2.5 ppm or more (live body weight) in four of the eight collections tested. Heptachlor was found to be present in all eight of the clam sample collections at concentrations ranging from 0.008 to 0.125 ppm.

The total acreage of productive clam flats in the estuary is 862.6 acres (Jerome, *et al.*, 1965). These flats are under the jurisdiction of Salisbury, with 25.2% (217.8 acres); Newburyport, with 61.5% (530.1 acres); and Newbury, with 13.3% (114.7 acres). Of this productive area, only a small percentage has been utilized, and harvested clams must first be processed at the Shellfish Purification Plant in Newburyport before sale. Considered together, the Salisbury, Newburyport, and Newbury flats have an estimated legal-size clam population of 73,379 bushels (Jerome, *et al.*, 1965). Since there is evidence that digging enhances the productivity of clam flats (Jerome, *et al.*, 1965), renewed digging of clams could easily increase the number of legal clams available for harvesting to approximately 100,000 bushels annually.

In 1964, the existing clam population and wholesale clam prices indicated that an annual revenue of $300,000 could be realized from clamming. Today, even without proper management, the total value could well exceed $500,000 (McCall, Massachusetts Department Public Health, personal communication) and, with management, might approach $1,000,000 annually (Jerome, *et al.*, 1965). The present revenue of $50,000 for the combined shellfish and clam worm (*Nereis virens)* harvest is very small compared to the expected value of the shellfish industry alone, if pollutional contamination were stopped.

Benthic macroinvertebrate data collected in the estuary in September-October, 1973, to augment existing data, are summarized in Table 43. Detailed data on abundances of organisms and percent composition are given in Appendix B. A synopsis of percentages of tolerant, facultative, and intolerant forms is given in Figures 21 and 22. "Tolerant", "facultative", and "intolerant" classifications are consistent with those used by the EPA (Environmental Protection Agency; 1973). Community differences around the watershed stand out quite vividly in these figures. The Merrimack,

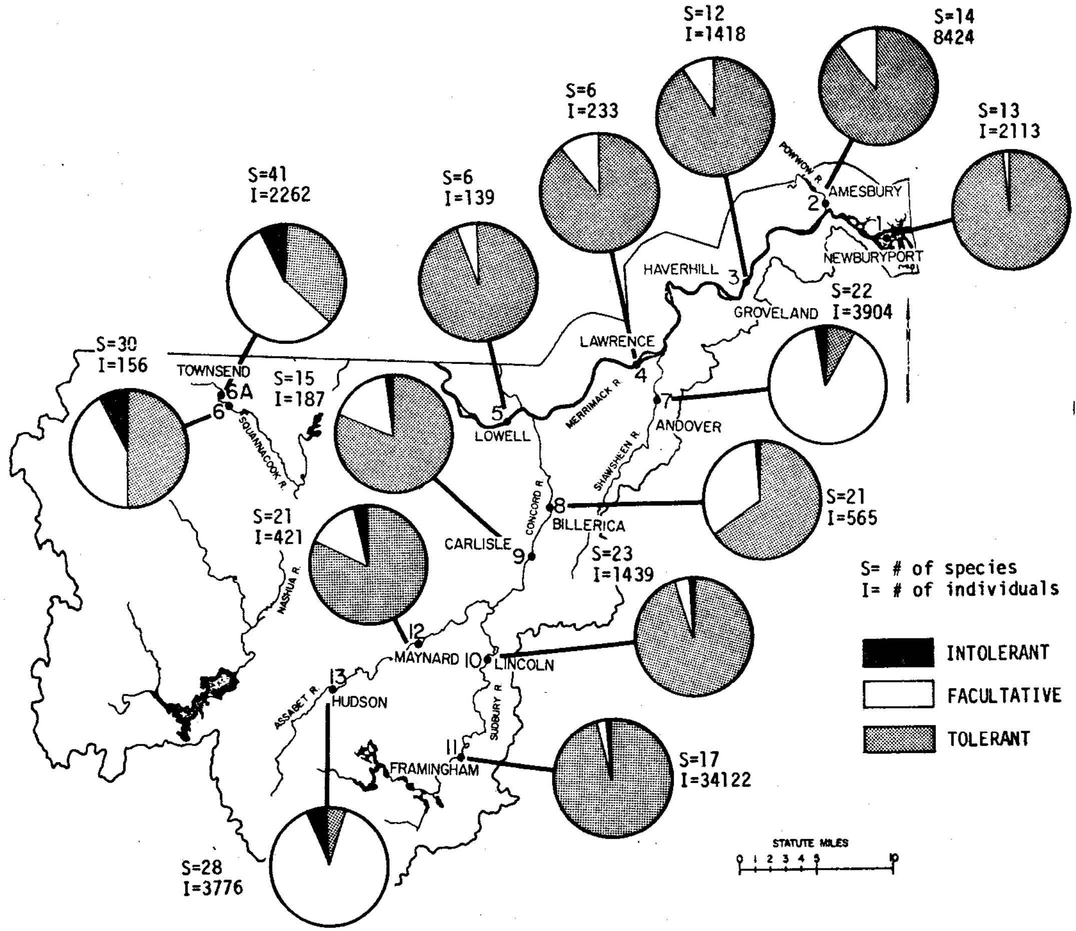


Figure 21. Percent composition (by # of individuals) of intolerant, facultative, and tolerant benthic invertebrates in Merrimack Watershed samples (September 10, 1973).

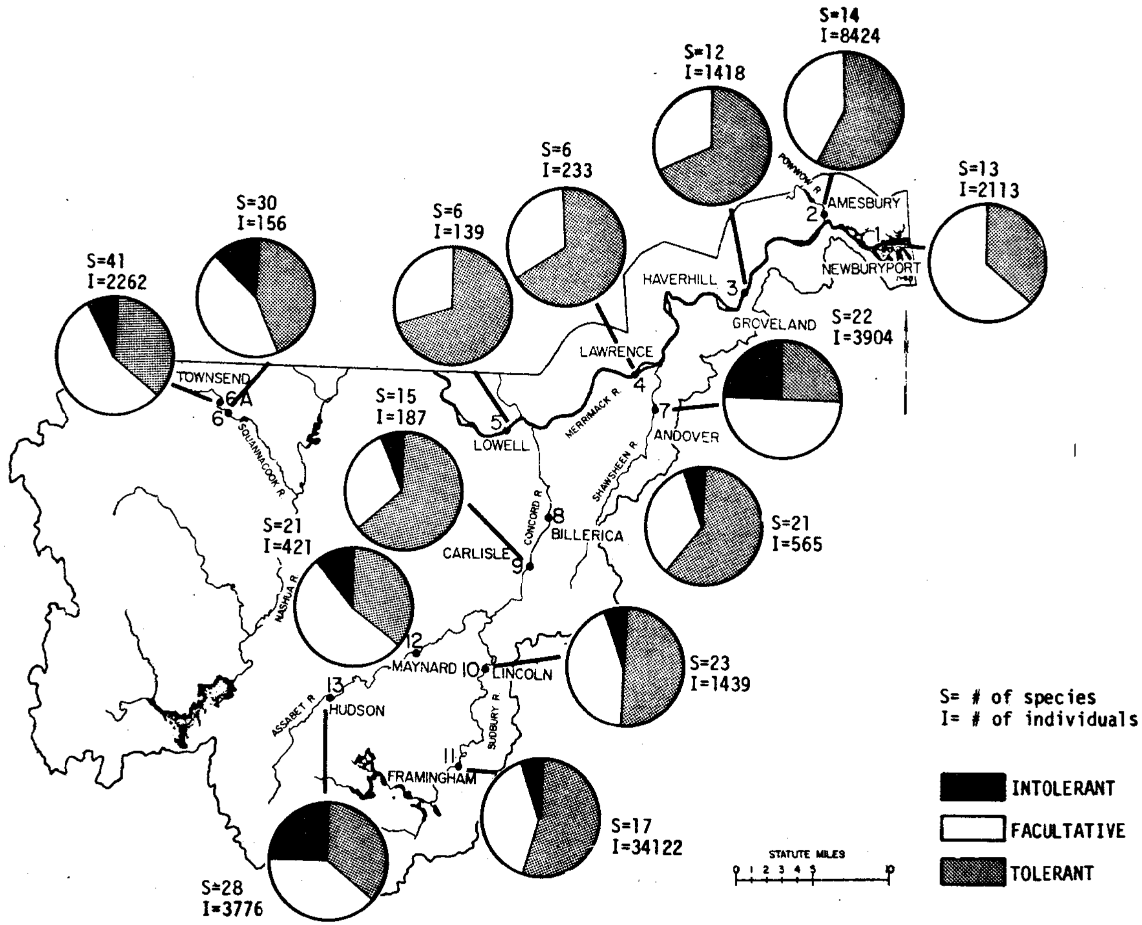


Figure 22. Percent composition (by # of species) of intolerant, facultative, and tolerant benthic invertebrates in Merrimack Watershed samples (September 10, 1973).

TABLE 42. PESTICIDE CONCENTRATIONS IN CLAM MEAT SAMPLES TAKEN AT NEWBURYPORT AND SALISBURY, MERRIMACK RIVER, 1964

(Jerome *et al.*, 1965)

DATE COLLECTED	SITE	HEPTACHLOR (ppm) (LBW)*	HEPTACHLOR EPOXIDE (ppm) (LBW)	**DIELDRIN OR DDE (ppm) (LBW)	DDT (ppm) (LBW)
June 26	P_1	No Test	0.100	0.420	1.180
26	P_2	No Test	1.530	1.500	0.460
July 10	P_1	0.033	No Test	No Test	0.008
10	P_2	0.027	No Test	No Test	0.016
July 20	P_1	0.125	No Test	No Test	0.050
20	P_2	0.108	No Test	No Test	0.012
July 30	P_1	No Test	2.500	None	None
30	P_1	No Test	2.500	None	None
30	P_2	No Test	2.800	None	None
30	P_2	No Test	2.750	None	None
September 8	P_1	0.100	No Test	No Test	0.033
8	P_2	0.100	No Test	No Test	0.025
December 28	P_1	0.070	None	None	None
28	P_2	0.008	None	None	None

*(LBW): Live Body Weight (ppm)
**Dieldrin--DDE: Not separable by method used

TABLE 43. SUMMARY OF BENTHIC INVERTEBRATES FROM SAMPLES TAKEN DURING SEPTEMBER - OCTOBER, 1973

TAXA	% TOTAL	TOTAL ABUNDANCE	FREQUENCY OF OCCURRENCE	OCCURRED AT STATIONS:
Hydra	1	1	.00169	8
Dugesia tigrina	9	1526	2.479	3, 6A, 7, 8, 9, 10, 11, 12, 13
Nematoda	12	160	.270	1, 2, 3, 6, 6A, 7, 8, 9, 10, 11, 12, 13
Bryozoan statoblasts	10	138	.233	1, 2, 3, 4, 8, 9, 10, 11, 12, 13
Stylaria sp.	8	121	.204	3, 6, 6A, 7, 8, 9, 10, 13
Pristina sp.	13	21452	36.154	2, 3, 4, 5, 6, 6A, 7, 8, 9, 10, 11, 12, 13
Slavina sp.	5	533	.901	3, 6A, 8, 12, 13
Limnodrilus sp.	14	21235	35.459	1, 2, 3, 4, 5, 6, 6A, 7, 8, 9, 10, 11, 12, 13
Monopylephorys sp.	1	892	1.407	1
Oligochaeta	7	28	.047	2, 6, 7, 8, 10, 12, 13
Nereis sp.	1	1	.00169	3
Nereis arenocoedanta	1	1094	1.749	1
Spiophanes sp.	1	74	.125	1
Prionospio sp.	1	8	.014	1
Scolecolepides sp.	1	2	.003	1
Cheumatopsyche sp.	5	6248	10.359	5, 6A, 7, 10, 13
Hydropsychidae	1	16	.027	6A
Leptoceridae	1	18	.030	6, 6A
Psychomyiid sp.	1	1	.00169	6
Psychomyiidae	2	136	.230	6, 6A

Continued

TABLE 43. (continued).

TAXA	% TOTAL	TOTAL ABUNDANCE	FREQUENCY OF OCCURRENCE	OCCURRED AT STATIONS:
Limnephilidae	2	67	.113	6, 6A
Hydroptilidae	1	1	.00168	6A
Orthotrichia sp.	1	5	.008	6A
Trichopteran	2	4	.007	6, 6A
Polycentropus sp.	1	6	.010	6
Berosus sp.	1	27	.046	6A
Psephenus sp.	2	4	.007	6, 6A
Scirtes sp.	1	2	.003	6A
Dubiraphia sp.	1	1	.00168	6
Promoresia sp.	1	665	1.024	6A
Stenelmis sp.	2	49	.083	7, 13
Elmidae	2	2	.003	8, 6A
Optioservus sp.	1	20	.034	6A
Ephemerella sp.	1	23	.039	6A
Paraleptophlebia sp.	2	11	.018	6, 6A
Baetidae	1	1	.00169	6
Ephemera sp.	1	22	.372	6
Stenonema sp.	3	176	.297	6A, 10, 13
Baetis sp.	1	6	.010	6A
Baetisca sp.	2	4	.007	6, 6A
Ephemyroptera	1	1	.00168	6A
Notonectidae	1	1	.00168	7
Ranatra sp.	0	0		

Continued

TABLE 43. (continued).

TAXA	% TOTAL	TOTAL ABUNDANCE	FREQUENCY OF OCCURRENCE	OCCURRED AT STATIONS:
Veliidae	1	1	.00168	6
Helobdella stagnalis	7	228	.385	3, 6, 8, 9, 10, 11, 12
Glossiphonia complanata	3	22	.037	3, 10, 11
Placobdella ordonata	5	15	.025	2, 8, 10, 12, 13
Glossiphoniidae	8	253	.428	2, 3, 8, 9, 10, 11, 12, 13
Piscicolidae	8	47	.079	2, 3, 7, 8, 10, 11, 12, 13
Cladocera	1	21	.035	10
Cyclops sp.	2	6	.010	9, 1
Asellus sp.	2	87	.147	7, 13
Lirceus sp.	2	12	.020	7, 13
Gammarus sp.	5	678	1.046	2, 6A, 7, 11, 13
Hyaella azteca	5	1185	2.003	6A, 8, 9, 10, 12
Marinogrammarus sp.	1	1	.00168	1
Orconectes sp.	1	1	.00168	7
Crangon septemspinosa	1	5	.008	1
Tandacea	1	5	.008	1
Simulidae	4	57	.096	6A, 10, 12, 13
Pentaneura sp.	5	20	.034	6, 7, 9, 12, 13
Tendipes sp.	6	43	.073	2, 4, 5, 6A, 10, 11
Cryptochironomous sp.	3	4	.007	6, 8, 9
Tendipedidae	13	859	1.251	2, 3, 4, 5, 6, 6A, 7, 8, 9, 10, 11, 12, 13
Probezzia sp.	5	42	.071	2, 5, 6, 6A, 7
Alluaudomyia sp.	2	2	.003	6, 6A

Continued

TABLE 43. (continued).

TAXA	% TOTAL	TOTAL ABUNDANCE	FREQUENCY OF OCCURRENCE	OCCURRED AT STATIONS:
Tabanidae	1	2	.003	6
Atherix sp.	2	31	.052	6, 6A
Chaoboros sp.	1	2	.003	4
Dipteran	2	3	.005	6, 6A
Lymnaea sp.	1	94	1.589	11
Amnicola sp.	5	27	.046	6, 6A, 7, 8, 10
Heliosoma sp.	4	10	.017	7, 10, 11, 12
Physa sp.	4	58	.098	2, 10, 11, 13
Campeloma decisum	2	12	.020	6; 12
Gastropoda	4	25	.042	7, 11, 12, 13
Unionidae	1	2	.003	8
Sphaeriidae	9	282	.476	2, 6, 6A, 7, 8, 9, 10, 11, 12
Mya arenaria	1	4	.007	1
Macoma balthica	1	8	.014	1
Mytlus edulis	1	13	.022	1
Lestes sp.	2	2	.003	7, 8
Ischnura sp.	1	12	.020	13
Hetaerina sp.	1	6	.0101	6A
Boyeria sp.	1	1	.00169	6A
Acroneura sp.	1	1	.00169	6A
Isoperla sp.	1	2	.003	6A
Climacia sp.	1	8	.014	13
Nymphula sp.	1	2	.003	13

2,39048

TOTAL INDIVIDUALS = 59,096

Concord, Sudbury, and lower reaches of the Assabet River are dominated by tolerant forms, both in taxa and numbers. The Squannacook, Shawsheen, and upper Assabet River, however, support abundant facultative, (intermediate sensitivity) and even tolerant (sensitive) populations of organisms. Earlier surveys in 1965, of at least two tributaries -- the Assabet and Concord Rivers (Massachusetts Water Resources Commission, 1973) -- indicated the presence of only tolerant forms (bloodworms and sludgeworms).

c) AQUATIC MACROPHYTES

As with all biological communities, the assemblage of aquatic macrophytes observed at a particular locale is the result of complex physical, chemical, and biological interactions. Physical factors such as light intensity, water temperature, water movement (waves and current), depth, and substrate type interact to govern their establishment, maintenance, and growth rate (MacKenthun and Ingram, 1967). In adjusting to their physical environment, three principal life modes have been adopted by aquatic plants. These are: 1) emergent species, 2) non-emergent species, and 3) free-floating species. Emergent species occupy shallow water, are rooted in the substrate and support foliage, seeds and mature fruit one or more feet above the water surface. Included in the emergent classification are groups such as waterlilies *(Nymphaeaceae)*, cattails *(Typhaceae)* and rushes *(Juncaceae)*. Non-emergent species often form the assemblage of plants growing furthest from shore. These forms exist entirely underwater and are attached to or rooted in the substrate. The pondweeds *(Najadaceae)* are typical of this group. Lastly, the free-floating species include such forms as duckweeds *(Lemnaceae)*. These forms are generally small, and their population must be constantly replaced from upstream sources (MacKenthun and Ingram, 1967; Hynes, 1970).

Changes in the physical environment can alter aquatic macrophyte communities. Such physical changes can include: 1) fluctuation in flow rate (caused by floods, drought, and flow augmentation and diversion by man), 2) changes in light transmission and 3) temperature fluctuations. Each of these parameters can act singly or in concert to induce community response. The rate and degree of such a response tends to vary directly with the magnitude of the physical change.

In addition to the physical parameters discussed above, chemical factors such as water hardness, or an associated parameter such as pH or calcium content (Hynes, 1970), and nutrients (MacKenthun and Ingram, 1967; Hynes, 1970) also influence the distribution and abundance of aquatic plant species. For example, Lohammer (1954) reports that leafy liverwort *(Fissidens* sp.) primarily occurs in enriched water in northern Europe, and it is particularly abundant in Doe Run, Kentucky, which is rich in nitrates and phosphates (Hinkley, 1963). It is also a common plant in the brickwork of English canals, where the water is usually very rich in nutrients (Hynes, 1970). Vannote and Ball (1972) note that, in the Red Cedar River, Michigan, macrophyte production has increased dramatically since 1957, apparently corresponding to an elevated nutrient supply. Prior to 1957, areas of substantial aquatic plant production in the Red Cedar River were limited to small zones of stream enrichment.

Finally, aquatic macrophytes interact, at least to a limited extent, among themselves and with other components of the biota (Hynes, 1970). For example, a channel cut from the River Schwarzwasser to ponds approximately 1 mile away was fully colonized by manna grass *(Glycera aquatica)* and water weed *(Elodea canadensis)* within a year (Walter, 1961). This colonization was rapid and completed in one step (Hynes, 1971). Occasionally, however, a limited amount of succession occurs in flowing waters. Minckley (1963) noted, that in Doe Run, Kentucky, water milfoil *(Myriophyllum heterophyllum)* occasionally became established on beds of leafy liverwort *(Fissidens julianus)* which were then smothered with silt and replaced, and that stonewort *(Nitella flexilis)* colonized the downstream end of a silt bank formed by pondweed *(Potomogeton diversifolius)*. However, such successions are generally minor, (Hynes, 1970). On the other hand, successions resembling those in still water may occur in man-made canals because of their controlled flow and constant water level (Narayanayya, 1928; Hynes, 1971).

Aquatic macrophytes provide food for waterfowl (Martin and Uhler, 1939), substrate for periphyton, and shelter and food for certain aquatic invertebrates and fish (Hynes, 1970). Some species such as the pondweeds are of enormous ecologic significance in the cycling of both nutrients and respiratory gases (Reid, 1961). Thus, alterations of the aquatic macrophyte community can have far reaching effects on the aquatic ecosystem.

In the streams under consideration, in the Massachusetts section of the Merrimack River basin, the interplay of environmental factors discussed above is evident. Fig. 23 (p. 135) shows the relative abundance and distribution of aquatic macrophyte species observed during the September-October 1973 survey. Seasonal effects were evident during the fall, 1973 survey as the aquatic macrophytes began to wither and lose color.

The mainstem of the Merrimack River and the associated Powwow River site exhibited a generally lower diversity and abundance of aquatic macrophytes than did the tributary streams. All of the communities identified were comprised primarily of emergent species. The aquatic macrophyte community was almost entirely confined to the narrow littoral zone. At Haverhill, the littoral area was substantially broader than at the other sites and there was a corresponding increase in aquatic macrophyte diversity and abundance. Backwater areas observed at these sites exhibited more diverse assemblages than littoral zones of the river. At Lowell and Lawrence, pickerelweed *(Pontedaria* spp.) and arrow arum *(Peltandra virginica)* were the dominant forms found on the mainstem. These plants have a very thick base and a well anchored root system by which they are adapted to the rigors of a river environment. Burr reed *(Sparganum* sp.) and water lilies were also found, but were very sparsely distributed. In back water areas, water lilies appeared to be dominant, but arrow arum and pickerelweed were also abundant. Wild rice appeared in the high littoral zone but was sparsely distributed. At Haverhill pickerelweed, pondweed and wild rice were very abundant. Hardstem bulrush *(Scirpus acutus)* was also found in abundance, and waterwort *(Elatine* sp), burr reed, spike rush *(Eleocharis* sp.), duck potato *(Sagittaria* sp.) and arrow arum occurred in lesser numbers. The Powwow River site, being a shallower stream with a larger littoral zone than the mainstem, had a greater abundance of aquatic macrophytes, but was comprised of similar species. Pickerelweed and wild rice were the dominant forms. Duck potato, burr reed, and bulrush were present. Although the mainstem is nutrient enriched, the physical characteristics of the environment (predominantly substrate instability, limited littoral area, and turbidity) appeared to limit the the aquatic macrophyte community. The Powwow River site, which is strongly influenced by Merrimack River water through tidal action, exhibited a more abundant aquatic plant community since it provided a more suitable physical habitat.

Thirty-seven taxa of vascular plants were collected from the surrounding marshy habitat of the Merrimack River estuary during 1971 (Table 44). All except marsh grass *(Spartina* spp.) and bulrush were found above mean high water. Fourteen of these species were widely distributed; the remainder were sporadic in occurrence or only collected once.

In the tributary system aquatic macrophyte communities were generally more diverse, and showed higher abundances than did the Merrimack and Powwow River Stations. This was

TABLE 44. VASCULAR PLANTS FOUND IN THE MERRIMACK RIVER ESTUARY (Normandeau Associates, Inc., 1971)

SCIENTIFIC NAME — COMMON NAME

**Acnida cannabina* L. Found in salt marshes and tidal shores.

**Acorus calamus* L. (Sweet flat or Flagroot) (older name for a reed) has an aromatic rhizome. Found in wet places and borders of quiet water. (Primarily found in freshwater).

Ambrosia artemisiifolia L. (Ragweed). Ubiquitous distribution.

Ammophila breviligulata Fern. (Beach grass). Found on dunes and in sandy habitats near the open coast.

Artemisia stelleriana Bess. (Dusty Miller). Found on sandy beaches and dunes.

Aster subulatus Michx. A plant of saline marshes.

**Atriplex patula* L. var. *hastata* (L.) Gray (Orach). Found in saline, brackish or rich soils both on the coast and inland.

Bulbostylis capillaris (L.) C. B. Clarke. A plant of dry open soil.

Cakile edentula (Biegl.) Hook. (Sea-rocket). Found on sandy gravelly beaches and seacoast.

Carex salina Wahlenb. A true halophyte found on saline or brackish shores.

Cyperus filiculmis Vahl var. *macilentis* Fern. (Limited distribution)

Distichlis spicata (L) Greene. (Spike grass). Grows in saline marshes.

Eleocharis acicularis (L.) R. & S. Commonly found on damp shores and low grounds.

Gnaphalium obtusifolium L. (Cat foot). Typically found in dry woods, clearings and on the edges of woods.

Continued

TABLE 44. (Continued)

Hudsonia tomentosa Nutt. (Beach heath, poverty grass). Found on sandy areas primarily near the coast.

Hypericum gentianoides (L.) BSP. (Orange grass). Found in sandy, sun baked soil.

**Juncus gerardi* Loisel. (Black grass). Saline areas and salt marshes.

Lathyrus japonicus Willd. (Beach Pea). Found on sandy beaches and dunes.

**Limonium carolinianum* (Walt.) Britt. (Sea-Lavender) L. or Nashii Small. Found in salt marshes almost exclusively.

Lythrum salicaria L. (Purple loosestrife). A plant of wet areas and river floodplains. This is considered a local nuisance in many New England areas. Often out competes other local species at times to their exclusion.

Plantago juncoides Lam. (Seaside Plantain). Mostly a maritime (shore side) species

Plantago oliganthos R. & S. (Seaside Plantago). Grows in salt marshes and saline or brackish shores.

Polygonella articulata (L.) Meisn. Found in dry sandy habitats.

Polygonum hydropiper L. Common Smartweed. Grows in damp soils.

**Potentilla egedei* Warmsk. var. *groenlandica* (Tratt.) Polunin. Normally grows by the seacoast.

**Salicornia europaea* L. (Glasswort or Samphire). Grows primarily in salt marshes occasionally found inland.

**Scirpus maritimus* L. var. *fernaldi* (Bickn.) Beetle (Bullrush). Occurs from saline to brackish marshes and extending from brackish to freshwater (tidal) areas.

**Scirpus validus* Vahl. Found in brackish or fresh shallow water and marshes.

Sium suave Walt. (Water Parsnip). A plant of meadows, wet thickets and muddy river banks. (Primarily freshwater).

**Solidago sempervirens* L. (Seaside Goldenrod). Found in saline, brackish or even freshwater habitats near the coast.

**Spartina alterniflora* Loisel. (Salt water cord grass). Grows on saline shores and marshes.

Continued

TABLE 44. (Continued)

**Spartina patens* (Ait.) Muhl. (Salt meadow grass). Grows on saline marshes and brackish shores.

Spergularia marina (L.) Griseb. Found in saline or brackish soils.

Triglochin maritima L. (Arrow-grass). Saline, brackish or fresh marshes and shores.

**Typha latifolia* L. (Cat-tail). Found in marshes as well as in shallow waters.

**Zizania aquatica* L. (Wild rice). River mouths growing in fresh to brackish waters. (Found in freshwater lakes and ponds.)

*indicates most widely distributed species largely due to greater availability of suitable habitat. It is apparent from comparisons among tributary rivers that streams with high nutrient loadings (Assabet, Sudbury, Shawsheen, and Concord) had a more abundant and diverse flora than was found in the Squannacook River which had substantially lower nutrient concentrations.

The communities present at the two sites on the Squannacook River differed as a result of contrasting physical regimes. Site 6A was a shallow, rapid current situation. The sandy areas dominated by wild celery *(Vallisneria americana)* which occurred very abundantly near the river banks. Also present in this environment was pondweed. In the rocky environment a more diverse assemblage with lower individual abundances was found. This assemblage consisted of buttercup *(Ranunculus purshii)*, water starwort *(Callitriche* sp.), spike rush and stonewort. At Station 6, the Squannacook was a much slower stream with deep pools and some backwaters. Aquatic plants were more abundant at Station 6 than at 6A. The aquatic vegetation community at Station 6A was comprised of a very abundant population of pondweeds, *(Potomogeton oakesianus* and *Potomogeton gramineus)*; duckweed occurred in abundance in the deep pools; Burr reeds were abundant in back water areas. Bush pondweed *(Najas* sp.), bulrush and pickerelweed were present along the course of the river. At both stations the aquatic vegetation was primarily non-emergent.

In general, physical conditions favorable for plant growth were present in the Squannacook River. The clear shallow water permitted good light penetration and the substrate provided a wide range of habitats for the growth of aquatic plants. However diversity and abundance was still lower than most other tributaries due to lower nutrient concentration.

At all sites observed on the Shawsheen River, prolific and diverse production of aquatic plants was noted. Non-emergent vegetation dominated the plant assemblage with pondweeds *(Potomogeton epihydrus, Potomogeton* spp.), hornwort *(Ceratophyllum demersum)* and waterweed *(Elodea canadensis)* being particularly abundant. Also abundant were leafy liverwort, stonewort, holly *(Ilex verticillata)*, and mud plantin *(Heterantheria dubia)*. Duck potato and pickerelweed were present along the littoral zones. Duckweed was very abundant and littered the stream surface.

The presence of such an abundant plant population, especially pondweed, is not surprising in view of the elevated nutrient levels observed in the Shawsheen River combined with its shallow depth. These characteristics provide

KEY TO FIGURE 23. AQUATIC MACROPHYTES

EMERGENT

#	SPECIES
1	*Pontedaria cordata*
2	*Sagittaria* sp.
3	*Zinsina aquatica*
4	*Peltandra virginica*
5	*Scirpus* sp.
6	*Scirpus acutus*
7	*Nymphae* sp.
8	*Cabomba caroliniana*
9	*Elatine* sp.
10	*Ilex verticulata*
11	*Polygonum* sp.
12	*Aracea* sp.

NON-EMERGENT

#	SPECIES
13	*Potomogeton* sp. (1)
14	*Potomogeton* sp. (2)
15	*Potomogeton oakesianus*
16	*Potomogeton gramineus*
17	*Potomogeton epihydrus*
18	*Potomogeton pusillus*
19	*Sparganum* sp.
20	*Elodea canadensis*
21	*Ceratophyllum demersum*
22	*Ceratophyllum* sp.
23	*Najas* sp.
24	*Callitriche* sp.
25	*Eleocharis* sp.
26	*Fontinalis* sp.
27	*Vallisneria americana*
28	*Ranunculus* sp.
29	*Fissidens* sp.
30	*Heterantharia dubia*
31	Unknown sp. (1)
32	Unknown sp. (2)

FLOATING

#	SPECIES
33	*Lemna minor*
34	*Wollfia* sp.

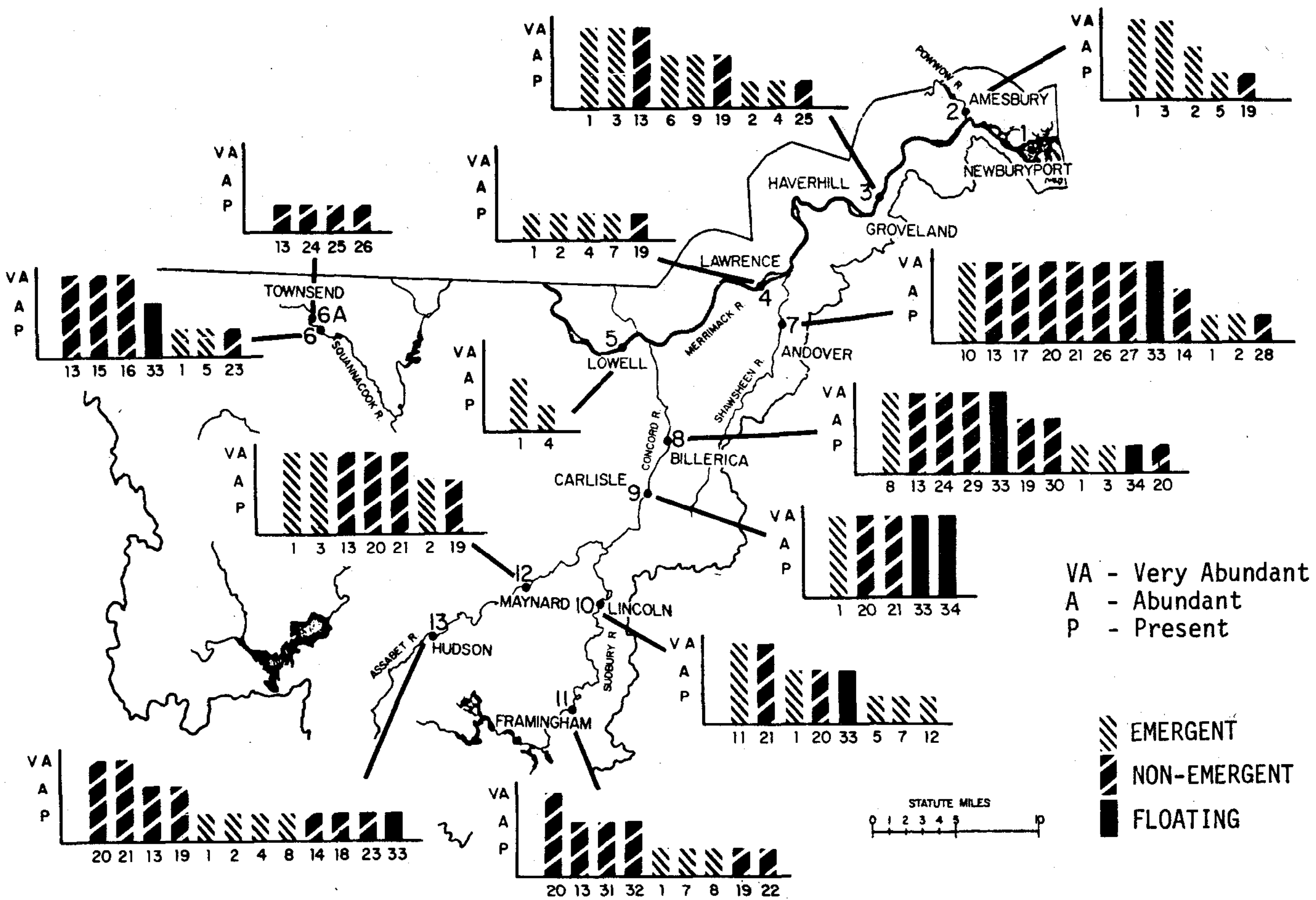


Figure 23. Relative abundance and distribution of aquatic macrophytes in the Merrimack River Basin (September - October, 1973).

abundant metabolic materials and light to all non-emergent aquatic macrophytes.

In the SUASCO system, the aquatic macrophyte population observed was a very abundant one. In the Concord and the lower portions of the Sudbury Rivers turbidity was high, but expansive littoral zones permitted substantial levels of aquatic macrophyte production. The Assabet River was quite clear and shallow, and this, combined with a high nutrient loading, permitted substantial aquatic plant production. Aquatic vegetation at both Station 12 and 13 on the Assabet River (see Figure 23) was abundant and diverse. At Station 12 emergent species such as pickerelweed and wild rice occurred in great abundance along the shore, while water weed and Hornwort covered the bottom in the low velocity areas. Upstream in areas of more rapid current, *Potomogeton* spp. covered the bottom in high abundance. Also occurring in substantial numbers burr reed and duckweed. Station 13, which was located nearer the headwaters of the Assabet, exhibited a greater diversity of aquatic vegetation. Again, non-emergent species dominated with water weed, hornwort, pondweed, and burr reed occurring in abundance. Bushy pondweed, pondweeds *(Potomogeton pusillus* and *Potomogeton* spp.), and fanwort *(Cabomba caroliniana)* were present in the non-emergent assemblage. Emergent species were duck potato, pickerelweed and arrow arum. Duckweed was present on the water surface.

Aquatic vegetation at the two sites sampled on the Sudbury River was also both abundant and diverse. The vegetation at Station 11 was less abundant and more sparsely distributed than at Station 10, but was dense where it occurred. At Station 11 the vegetation was primarily non-emergent and dominated by water weed and abundant stands of *Potomogeton* spp. Two unidentifiable non-emergent species also occurred in abundance. Other species present were fan-wort, water lily, pickerelweed and burr reed.

Concord River stations were dominated by non-emergent forms in rapid current areas, while both emergent and non-emergent varieties were abundant in marshy and impounded settings. The Concord River at Station 8 (see Figure 23) in North Billerica consisted of a section of rapidly running stream, terminating in a mill impoundment. In the rapid current area pondweed and water starwort were very abundant. Burr reed was abundant along the banks with water weed and pickerelweed present. Fanwort was very abundant in the downstream pond. Wild rice was present along the river banks and became very abundant on the banks of the downstream millpond. Duckweed and watermeal (*Wolffia* sp.) were very abundant on the river surface and were collected in large floating masses downstream in the millpond. Observational evidence at this site indicates eutrophication to be progressing rapidly in the mill pond, with a corresponding high production of aquatic vegetation.

Station 9 located on the Concord River, in the marshy setting of the Great Meadows National Wildlife Refuge at Carlisle, Massachusetts, was dominated by waterweed and hornwort which were very abundant in the littoral zone and completely covered the substrate. Pickerelweed was very abundant in the upper littoral zone, and great sheets of duckweed were found on the river surface in still water areas.

d) FINFISH

In the development of any multiple use water resource, the proposed and existing fishery must be given substantial consideration due to its economic, recreational, and aesthetic importance. Historically, the Merrimack River has been the location of a highly productive fishery. The first settlers utilized what must have been a fantastic anadromous fish resource, whose principal members were American shad *(Alosa sapidissima)* and Atlantic salmon *(Salmo salar)*. In 1634, William Wood, noting the general physical characteristics of the Merrimack River, its broad marshes, the presence of upriver falls and its outstanding fish population stated, "In this river is sturgeon, salmon, and bass, and diverse other kinds of fish" (from Currier, 1902). With the development of the area, however, the fishery declined. In 1887, the sturgeon fishery, which had lasted over 200 years, ended with the last successful commercial sturgeon catch (Jerome, *et al.*, 1965). The shad and salmon fisheries were dealt severe blows by the construction of impassable dams at Lowell and Lawrence, Massachusetts as well as on tributary streams. By 1898 only a few salmon runs were observed, and after 1901 no further mention of the salmon fishery is found (Jerome *et al.*, 1965). In addition to the eradication of the anadromous fishes, the resident fish population has also suffered through human modification of the environment.

The massachusetts section of the Merrimack River is a warm water fishery in poor condition. Data from Wightman and Newell (1971) indicate that the degradation of this fishery begins at Garvin Falls above Manchester, New Hampshire with a reduction of yellow perch *(Perca flavescens)* and pumpkinseed sunfish *(Lepomis gibbosus)* populations and a dramatic increase of brown bullhead *(Ictalurus nebulosus)* and white sucker *(Catostomus commersoni)* populations. To assess the mechanics of this degradation one must consider the various ecologic factors which interact with the finfish community, and dictate its abundance and composition. As with the other biologic communities (plankton, aquatic macrophytes, and benthic invertebrates) discussed earlier, the finfish community is the result of past and ongoing, physical, chemical and biological conditions in the river basin. The angler is familiar with the necessity of suitable physical conditions (water movement, substrate, turbidity, temperature, and type and abundance of aquatic vegetation) when seeking a particular species or type of fish. Less obvious to the fisherman are the chemical factors (dissolved oxygen, and toxic materials) and the biologic factors (competition for food and space, predation of juveniles and eggs) which play a vital role in determining where fish can exist.

The stability of river flow regime is an important environmental factor. Unusually high water in winter can be deleterious to trout by destroying eggs and small individuals (McFadden and Cooper, 1962). Particularly heavy flooding can even kill large individuals (Hynes, 1971). In the Des Moines River, Iowa, Starret (1951) showed the importance of high discharge periods to the biology of small minnows (cyprinids). This medium size river responded rapidly to periods of high rainfall. This response usually occurred in May or June, but climatologic abberations induced such a reaction at other times.

Since minnows spawn at various times, and high water favors spawning, the timing of heavy rain fall periods influences the relative and absolute abundance of competing species. It seems likely that similar interspecific relationships occur in other rivers with unstable flows. All of the tributary streams in the present study (Squannacook, Shawsheen, Powwow, Assabet, Sudbury and Concord) can be included in this category.

Another important aspect of fluctuating discharge is occasional or seasonal stream subsidence, leaving only isolated pools or no water at all at the surface. The creation of stagnant pools exposes fish to high temperatures and land based predators, and often to depleted oxygen levels. Most species cannot survive these conditions, although the creek chub *(Semotilus atromaculatus)*, white crappie *(Pomoxis annularis)*, bluegill *(Lepomis macrochirus)*, and longear sunfish *(L. megalotis)*, big mouth shiner *(Notropis dorsalis)*, and the bullhead *(Ameiurus melas)*, may do so (Hynes, 1970). Following a return to normal conditions however, these and other species will recolonize the defaunated area from a more stable refugium. Larimore *et al.*, (1959) observed this rapid recolonization process in Smiths Branch, Illinois.

A few fish, particularly small benthic species, are more or less confined to rocky or stony substrata. These include, for example, all those with ventral suckers and friction plates, and cryptic fishes such as sculpins (Cottidae) and loaches (Cobitidae). Many others are also fairly definitely associated with a specific substratum, e.g. the gudgeon *(Gobio gobio)* is associated with gravel (Bernet, 1960), the sand darter *(Ammocrypta beanii)* and a number of small minnows with sand (Hubbs and Walker, 1942; Metcalf, 1959), and the mudfish *(Umbra limi)* with thick marginal vegetation (Peckham and Dineen, 1957). But for the majority of species the nature of the substratum is apparently of little direct consequence except at times of breeding. Current velocity and water depth seem to be of greater importance (Cleary and Greenback, 1954).

Turbidity can influence patterns of inter-and intra-specific abundance and distribution. White crappie tolerate turbid conditions better than black crappie *(Pomoxis nigromaculatus)* (Neal, 1963). This is well documented in the literature (see Goodson, 1966). All Oklahoma lakes with only black crappie are clear, and most lakes with only white crappie are turbid. A few clear lakes and many turbid lakes have mixed populations with black crappie predominating in the clear waters and white crappie in the more turbid ones (Hull *et al.*, 1954). Visual feeding fish, such as chain pickerel *(Esox niger)*, smallmouth bass *)Micropterus dolomieui)*, and most other gamefish, need less turbid water than tactile feeders such as brown bullhead, white sucker, and other rough fish (Hynes, 1971).

There is abundant data in the literature on temperature tolerance and preferences of various fish species, especially with regard to heated effluent-induced distribution changes. As an example, largemouth bass *(Micropterus salmoides)* can tolerate, and grow more rapidly in warmer water than brown trout *(Salmo trutta)*. The bulk of the Merrimack River Basin in Massachusetts is a warm water fishery with some marginal cold water streams (the Squannacook, Assabet, and Shawsheen).

Water chemistry is another important determinant of abundance distribution and behavior. Fish species vary in their tolerance of, and preference for, various dissolved constituents. Radtke and Turner (1967) found that more upstream migration of striped bass *(Roccus saxatilis)* occurred when total dissolved solids were low in concentration. Also, lower concentrations were required for spawning than for moving upstream. Eisley (1965) subjected five species of juvenile estuarine fish to various concentrations of synthetic detergent. He found that mummichogs *(Fundulus heteroclitus)* were the most resistent followed by eels *(Anguilla rostrata)*, winter flounder *(Pseudopleuronectes americanus)*, and silversides *Menidia menidia)*. He also showed that elevated concentrations of synthetic detergent slowed growth in sunfish.

Although fish can withstand a wide range of pH values and corresponding hardness and alkalinity (Hynes, 1970), Freeman and Everhart (1971) found that the toxicity of aluminum hydroxide to rainbow trout *(Salmo gairdneri)* were pH dependent, with increased toxicities at depressed pH values. Ellis (1937) states that a dissolved oxygen level of at least 5.0 ppm is required for a varied fish fauna. Lowered levels of dissolved oxygen stimulate increased gill pumping rates which can act synergystically with dissolved toxic materials to decrease their toxic threshold (Lloyd, 1961). Even in conditions where the mean level of dissolved oxygen is fairly high, if it fluctuates strongly, the fish population may not be as viable as the mean level of dissolved oxygen would indicate (Stewart, *et al.*, 1967).

Chlorination of treated sewage effluent for the removal of harmful bacteria can have detrimental effects on the fisheries population of a river. Tsai (1971) after studying water quality below 156 secondary wastewater treatment plants found that total chlorine and turbidity appeared to be the major cause of reduced fish communities below outfalls. These findings were supported by Arora *et al.* (1970) and Krock and Mason (1971). The toxicity range of free, available chlorine ($96hrTL_{50}$) is .005 - 0.100 ppm, with trout being the most sensitive and the fathead minnow *(Pimphales promelas)* the least sensitive of the species tested (Krock and Mason, 1971; Pike, 1971; Basch *et al.*, 1971; Arthur and Eaton, 1971; Dandy, 1972). Penzes (1971) reported acutely lethal levels of chlorine (0.15 - 1.4 ppm) destroyed epithelial cells in the gills of fish.

Competition for food among various fish species is extremely important (Hynes, 1971). In three Minnesota lakes, carp competed with bluegill for insects, entomostracans, and plant material; sheepshead *(Aplodinotus grunniens)* competed for insects; and black crappie and white crappie competed for entomostracans (Scidmore and Woods, 1960). Bluegill and grayling *(Thymallus arcticus)* in Ford Lake, Michigan, fed largely upon the same groups of invertebrates; the grayling population had been decreasing prior to these observations (Leonard, 1940). Bluegill in Lake Havasu competed with fingerling bass for forage fish less than one inch long (Belad 1954). Food alone, however, is generally not limiting in a river system (Hynes, 1970).

Observations of streams in the Massachusetts section of the Merrimack River basin show that there is considerable habitat diversity. Each river has a variety of current velocities, deep and shallow areas, and varying turbidity, stands of aquatic vegetation and substrata. In the case of the Squannacook, Shawsheen, and Assabet Rivers the upstream sections are also substantially colder than downstream sections. In an unspoiled river system one would expect to find a diversity of fish life corresponding to the diversity of the physical habitat. This correlation has not usually been found in the Merrimack River watershed, however. Figure 24 depicts the relative abundance of resident game, pan, forage, and rough fish present in the rivers under consideration. A more detailed amplification is given in Table 45.

The Massachusetts section of the Merrimack River is dominated by rough fish, principally white sucker, brown bullhead, and carp *(Cyprinus carpio)*; also present are white catfish *(Ictalurus catus)* and goldfish *(Carassius auratus)*. These comprise 40.5 percent of the total numerical abundance and over 80 percent of the total weight. Fish of interest or direct use to the angler include game fish such as chain pickerel *(Esox niger)*, largemouth bass, and white perch *(Morone americana)*, pan fish such as pumpkinseed sunfish, bluegill, yellow persh, black crappie, and banded sunfish *(Enneacanthus obesus)*, and forage fish such as golden shiner *(Notemigonus crysoleucas)*, spottail shiner *(Notropius hudsonius)*, and fallfish (*Semotilus corporalis)*. These species comprise approximately 59.5% of the total numerical abundance, but only 20 percent of the total weight (Oatis and Bridges, 1969).

Two major controlling factors appear to dominate the Merrimack River finfish community. With inputs of organic pollution, the diversity of stream benthos is dramatically lowered. The benthic species removed are those with a generally epifaunal, non-cryptic life mode (e.g. stoneflies, mayflies, etc.). Thus, in polluted stretches of the river visual feeders such as game, pan, and forage fish are unable to feed successfully. Correspondingly those benthic species which have an infaunal, cryptic life mode (e.g. oligochaetes, leeches, etc.) proliferate, and rough fish such as brown bullhead, white sucker, and carp have an abundant food source. As these rough fish become dominant they exert predation pressure on the eggs and juveniles of the already food limited desirable species and further reduce their population. In addition, river contamination by municipal wastes lowers the level of dissolved oxygen to critical levels (at or below 5 ppm) by increasing biological oxygen demand and stimulating algal production. Such a reduction in dissolved oxygen can be directly lethal to active species or can act synergystically with toxic materials present in the river, stimulating faster gill pumping, which results in a subsequent increased rate of toxicant uptake. In addition, dissolved

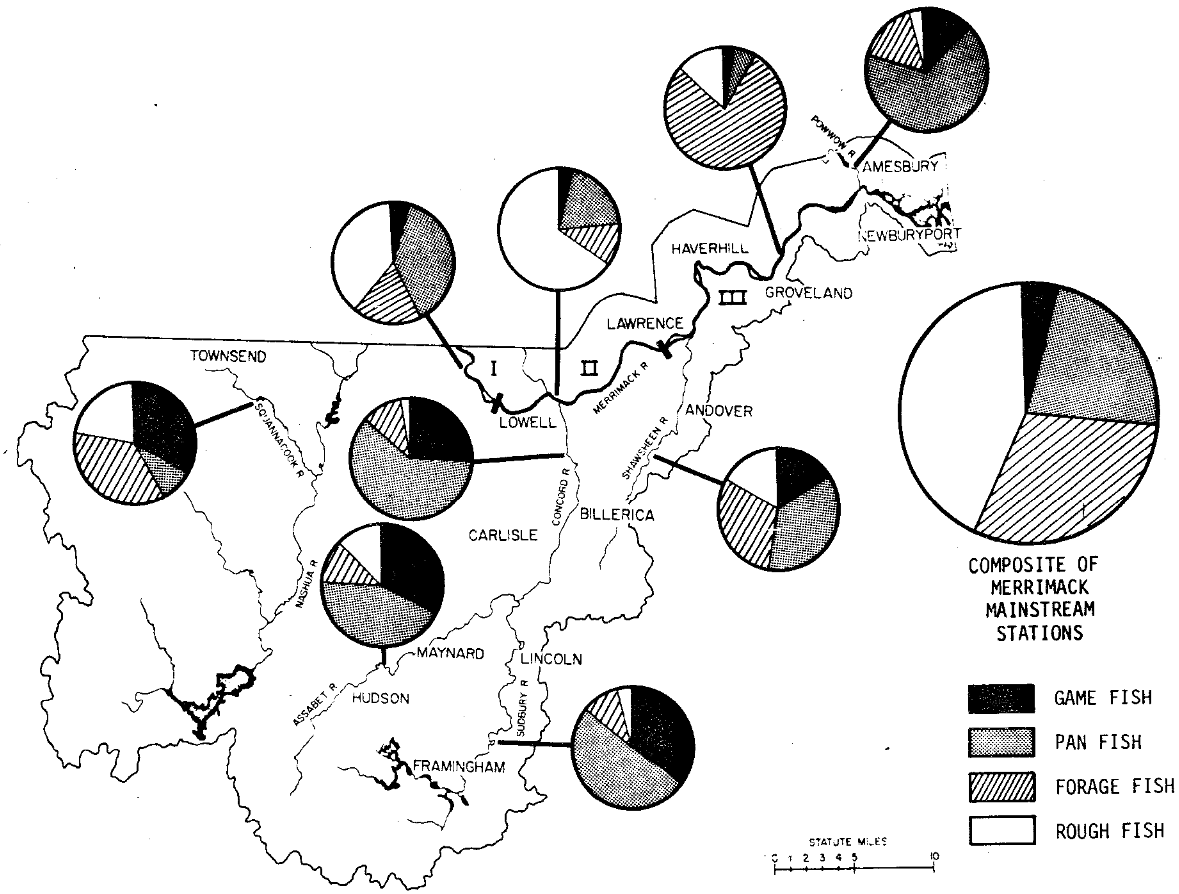


Figure 24. Relative abundance of fish groups in the Merrimack River Basin (mainstem data from Oatis and Bridges, 1968: tributary data from Mass. Div. Fish and Game, 1953).

TABLE 45. PERCENTAGE COMPOSITION BY RIVER OF FISH SPECIES IN THE MERRIMACK RIVER BASIN

GAMEFISH	MERRIMACK MAINSTEM ALL STATIONS[1]	SQUANNACOOK[2]	SHAWSHEEN[2]	POWWOW[2]	ASSABET[2]	SUDBURY[2]	CONCORD[2]	ZONE I MAINSTEM[1]	ZONE II MAINSTEM[1]	ZONE III MAINSTEM[1]
Brown trout	--	10.7	1.2	--	0.2	--	--	--	--	--
Brook trout	--	3.1	.03	--	3.0	--	--	--	--	--
Rainbow trout	--	1.6	0.3	--	0.3	--	--	--	--	--
Chain pickerel	0.7	17.5	7.8	8.7	5.6	19.9	20.7	1.8	0.2	--
Largemouth bass	1.3	--	0.5	0.3	0.4	4.7	2.3	1.4	1.4	1.1
Smallmouth bass	--	--	.03	0.3	0.3	--	--	--	--	--
White perch	0.9	--	--	4.5	13.4	3.1	0.8	1.4	0.5	1.1
Redfin pickerel[3]	--	--	6.9	--	10.1	7.7	2.6	--	--	--
TOTAL	2.9	32.3	16.8	13.8	33.3	35.4	26.4	4.6	2.1	2.2
PAN FISH										
Banded sunfish	0.1	0.5	1.2	--	0.6	3.5	0.5	0.4	--	--
Pumpkinseed	15.0	7.4	10.8	46.2	4.6	7.2	15.0	26.7	15.8	2.5
Bluegill	4.9	--	1.1	--	13.1	27.3	33.0	10.5	2.7	1.6
Yellowbelly sunfish	--	--	11.2	1.5	1.6	1.3	--	--	--	--
Black crappie	0.2	--	--	0.3	12.1	3.8	2.2	0.2	--	0.5
Yellow perch	2.5	1.0	12.2	22.6	10.8	8.0	9.4	1.3	4.3	1.9
TOTAL	22.8	8.9	36.5	70.6	42.3	51.1	60.1	39.1	22.8	6.5

Continued

TABLE 45. CONTINUED

	MERRIMACK MAINSTEM ALL STATIONS[1]	SQUANNACOOK[2]	SHAWSHEEN[2]	POWWOW[2]	ASSABET[2]	SUDBURY[2]	CONCORD[2]	ZONE I MAINSTEM[1]	ZONE II MAINSTEM[1]	ZONE III MAINSTEM[1]
FORAGE FISH										
Fallfish	1.2	23.1	4.2	--	2.9	0.6	--	2.4	0.5	0.3
Blacknose dace	--	0.5	--	--	--	1.0	.05	--	--	--
Longnose dace	--	7.1	--	--	--	--	--	--	--	--
Lake chubsucker	--	1.5	10.5	8.7	7.5	2.4	0.9	--	--	--
Johnny darter	--	--	1.5	0.6	0.4	--	0.1	--	--	--
Golden shiner	11.7	--	15.4	4.5	1.3	4.4	11.1	7.7	10.2	17.4
Spottail shiner	20.9	--	--	--	--	--	--	2.7	--	59.9
Common shiner	--	3.4	--	--	--	--	--	--	--	--
TOTAL	33.8	36.3	31.6	13.8	12.2	8.4	12.15	12.8	10.7	77.6
ROUGH FISH										
White catfish	.07	--	--	--	--	--	--	0.2	--	--
White sucker	26.7	21.6	6.8	--	5.3	.04	.05	25.2	50.6	4.8
Brown bullhead	6.6	0.2	5.7	1.8	1.4	4.1	1.3	13.0	2.7	4.3
Yellow bullhead	1.1	0.9	--	--	5.5	0.5	--	2.3	0.7	0.4
Carp	5.7	--	--	--	--	--	--	2.6	10.4	4.2
Goldfish	.07	--	--	--	--	--	--	0.2	--	--
American eel[4]	--	--	2.6	--	0.3	0.5	--	--	--	--
TOTAL	40.5	22.5	15.1	1.8	12.2	5.1	1.35	43.5	64.4	13.7

[1] Oatis and Bridges (1969)
[2] Massachusetts Division of Fisheries and Game (1953)
[3] Small, but sometimes considered a gamefish (pers. comm., P. Wightman, 1974)
[4] Utilized for food in some areas (Pers. comm., P. Wightman, 1974)

oxygen levels will be avoided by species requiring large amounts of dissolved oxygen (generally the game species). Some undesirable species such as the brown bullhead have a greater tolerance for low levels of dissolved oxygen and, therefore, have a competitive advantage over less tolerant, but more desirable species.

Jerome *et al.*, (1965) completed an extensive year-long survey of the inshore fishes frequenting the Merrimack River Estuary from the ocean at Plum Island upriver to predominantly freshwater at the Artichoke River. Seine samples were taken monthly at five sites along the length of the Merrimack River Estuary. The results of this sampling are compiled in Table 46 (see Figure 25 for location of Stations). Seventeen species of fish were captured, but four species: American sand launce *(Ammodytes americanus)*, mummichog *(Fundulus heteroclitus)*, blueback herring *(Pomobolus aestivalis)*, and alewife *(Alosa pseudoharengus)* comprised 99% of all fish captured.

The American sand launce was the most abundant species captured, but was not found in salinities of less than 25 $^{o}/oo$. Blueback herring and alewife were abundant at all stations. These species tolerate a complete range of salinity variation, as does mummichog, although it was found only in large numbers at the three inshore stations. Silversides and smelt *(Osmerus mordax)* were seasonally abundant at the higher salinity stations. Carp, brown bullhead, spottail shiners, and bluegills were the only freshwater fish seined throughout the year. All four species were taken at the Artichoke River station.

Jerome, *et al.* (1965) took monthly trawl samples from three stations (see Figure 25), one of which was located within the estuary. Of the 19 species captured, only five species (the winter flounder, striped bass, pollock *(Pollachius virens)*, sea raven *(Hemitripterus americanus)*, and lumpfish *(Cyclopterus lumpus)* were taken within the estuary. The winter flounder was the only fish taken in abundance at the inshore station. A complete list of all species taken by various methods is listed in Jerome *et al.* (1965).

The tributary streams under consideration are, in general, numerically dominated by game fish (13.8 to 35.4 percent), panfish (8.9 to 70.6 percent), and forage fish (8.4 to 36.3 percent; see Table 45 and Figure 24. The Massachusetts Division of Fisheries and Game (1953) conducted a survey of the fishery existing in the Squannacook River basin in 1953 (Massachusetts Division of Fisheries and Game, 1954). Although this data is slightly over 20 years old at

TABLE 46. MERRIMACK RIVER ESTUARY FISH SURVEY, 1964

(Condensed from Jerome, *et al.*, 1965)

TOTAL NUMBER OF SPECIMENS CAPTURED PER THREE MONTHS, RANKED BY ABUNDANCE AT EACH STATION

	COAST GUARD COVE					BADGER'S ROCKS					COFFIN POINT					CARR'S ISLAND					ARTICHOKE RIVER				
SPECIES	RANK	A	B	C	D	RANK	A	B	C	D	RANK	A	B	C	D	RANK	A	B	C	D	RANK	A	B	C	D
SQUIRREL HAKE	7			1																					
AMERICAN SAND LANCE	1		9120	4387	6768	2		10	12	1105	5		11												
THREESPINE STICKLEBACK	6		7			7			1		9		1												
AMERICAN SMELT	5			8		5			123		4			1	43	5		17		5					
ATLANTIC SILVERSIDE	4		1	25		4			99	68	5				11	4			51						
BLUEBACK HERRING	2			1132	219	1			1981	1761	1			4280		1		2	772	32	3			177	36
ALEWIFE	3			400		3			529	16	3			70		3		15	151	43	2		6	2036	6
MUMMICHOG						6		2			2		227	1976	76	2		133	140	10	1		9979	467	82
NORTHERN PIPEFISH											8			2											
WINTER FLOUNDER											6		1	3											
NINESPINE STICKLEBACK											9		1			8	1		1		9				1
WHITE PERCH											7		1		2	7		2	1	3	5			5	1
BLUEGILL											9		1								6		4	1	
AMERICAN EEL																6		2	5		7		1	3	
BROWN BULLHEAD																					8		2		
SPOTTAIL SHINER																8		2			4		14	20	
CARP																					9		1		

A = January, February, March B = April, May, June C = July, August, September D = October, November, December

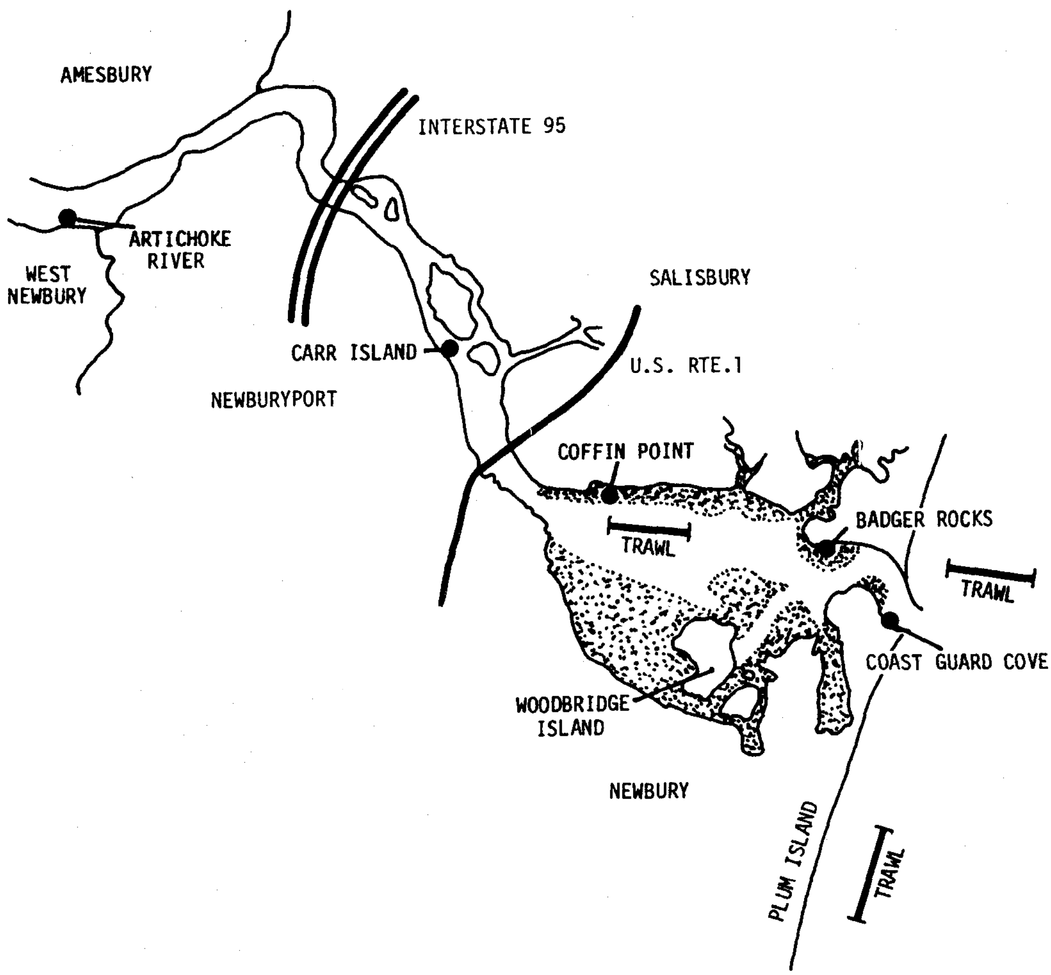


Figure 25. Location of seining and trawl stations in the Merrimack river Estuary (Jerome, et al., 1965).

the time of this writing, the lack of significant changes in the demography of the Squannacook basin, along with continued trout stocking and angler success, indicate a fairly stable fishery. Game and forage fish comprised 32.3 and 36.3 percent of the total abundance respectively. Chain pickerel and brown trout dominated the gamefish in abundance, while fallfish and longnose dace *(Rhinichthys cataractae)* were the dominant forage fish. This is essentially a salmonid (trout) fishery. It is likely that brown trout have been replaced by rainbow trout due to increased stocking efforts (Personal communication, R. W. Dyer, 1974). Although conditions are not optimal (low summer flows and high temperatures) for trout, they do survive in appreciable numbers. The abundance of aquatic plants and large amounts of overhanging vegetation provide a good fish habitat as does the variety of flow velocities and water depths.

Data from the 1953 (Massachusetts Division of Fisheries and Game, 1953) fisheries survey for the Shawsheen River show that its fishery is dominated by pan and forage fish, comprising 36.5 and 31.6 percent of the total abundance respectively. The fisheries habitat appears to be good. Aquatic vegetation is abundant, and many different hydrologic regimes are available. The presence of trout indicates a marginally cold water situation with sufficient oxygen to support a good fish fauna.

Data (Massachusetts Division of Fisheries and Game, 1953) on fish populations in the Powwow River is available for only one station upstream of Lake Gardner. Panfish were definitely dominant, comprising 70.6 percent of the total catch; game and forage fish each made up 13.8 percent, while rough fish comprised only 1.8 percent. This upstream fishery appears to be a healthy warmwater environment dominated by desirable fish species. The zone below Lake Gardner, being strongly influenced by the Merrimack River, is likely to have a greater abundance of rough fish.

The Assabet River in 1953 supported a relatively healthy warm water fishery with a cold-water salmonid fishery near its headwaters. In general, game (33.3 percent), pan (42.3 percent), and forage fish (12.2 percent) comprise the major portion of the fishery and a diverse assemblage was generally present at all stations sampled. The fishery does appear to become somewhat downgraded, proceeding downstream, as trout no longer occur and white sucker increase in abundance with a corresponding decrease in the abundance of a variety of forage and pan fish.

Data from the 1953 (Massachusetts Division of Fisheries and Wildlife) indicate a fairly healthy warm water fishery in the Sudbury River. Trash fish such as white sucker and brown bullhead occur in abundance only in the upstream stretches, particularly in the reservoirs. Downstream sections were dominated by pan fish. The overall fishery was comprised of 35.4 percent gamefish, 51.1 percent panfish and 8.1 percent forage fish.

Like the Sudbury, the Concord River fishery is dominated by panfish, but it also has an abundant chain pickerel population (20.7 percent). Rough fish were not found to be abundant. The overall fishery was comprised of 26.4 percent gamefish, 60.1 percent panfish, 12.15 percent forage fish, and 1.35 percent rough fish.

Many fish occupy a high trophic level, and because of this they are often the repository of materials which have been biomagnified through the food chain. Due to recent emphasis on mercurial contamination of fish flesh, studies have been conducted by the Massachusetts Department of Fish and Game (1971) and the New Hampshire Fish and Game Department (Wightman and Newell, 1971) to ascertain the degree of mercurial contamination of fish flesh. Table 47 contains the results of these studies.

Of the 76 individuals analyzed, 19 had a mercury content above the maximum acceptable tissue concentration of 0.0005 ppm (Environmental Protection Agency, 1973). This indicates that mercury is entering the food chain and being biomagnified. The concentration of mercury represents a public health hazard and could negate the worth of the existing fishery to a large degree. There appears to be a mercury contamination problem throughout the length of the Merrimack in that chain pickerel were consistently above the EPA (1973) standard of 0.0005 ppm (dry weight).

Chlorinated hydrocarbon compounds have received some study in the Merrimack River Basin. PCB's (polychlorinated biphenyls) as well as pesticides have been found to accumulate through the food chain. Merrimack River fish illustrate this phenomenon well. Arochlor 1248 (a PCB compound) was detected in fish collected at Haverhill at levels of 22.7 ppm, dry weight (Lyman, Noyes and Heeley, in preparation). This is far in excess of EPA (1973) standards for PCB's in fish tissue (maximum permissable level, 0.5 ppm). PCB levels in fish taken in 1971 at Lowell, Massachusetts, also exceeded EPA (1973) standards (Table 48).

TABLE 47. MERCURIAL CONTAMINATION OF MERRIMACK RIVER FISH IN NEW HAMPSHIRE AND MASSACHUSETTS

LOCATION	SPECIES	N	Hg (PPM) $\bar{X}$	Hg (PPM) RANGE
New Hampshire[1] Stations (Webster Place, N. H. to Nashua, N. H.)	Chain pickerel	10	.81	.46-1.8
	Smallmouth bass	4	.46	.17-0.85
	Yellow perch	12	.43	.13-1.10
	Golden Shiner	4	.37	.16-0.56
	Pumpkinseed	10	.28	.01-0.45
	White perch	9	.27	.04-0.75
	Fallfish	1	.22	---
	White sucker	10	.21	.09-0.40
	Brown bullhead	6	.16	.01-0.54
New Hampshire - Massachusetts[1] State Line	Yellow perch	2	.26	.20-0.32
	White sucker	2	.36	.33-0.40
	Brown bullhead	4	.35	.08-0.72
Lowell, Massachusetts[2]	Largemouth bass	1	.62	---
	Black crappie	1	.49	---

1 Data from Wightman and Newell (1971).

2 Data from Massachusetts Division of Fisheries and Game (1971).

TABLE 48. CONCENTRATION OF POLYCHLORINATED BIPHENYLS (PCB) IN FISH COLLECTED FROM THE MERRIMACK RIVER AT LOWELL, MASSACHUSETTS BY THE U. S. BUREAU OF SPORT FISHERIES AND WILDLIFE (1970-71)

(Lyman, Noyes and Heeley, in press)

YEAR	# SPECIMEN	(PPM)
1970	1 White Sucker	5.47
	1 White Sucker	4.90
	1 Pumpkinseed Sunfish	1.87
	1 Yellow Perch	6.12
1971	1 White Sucker	13.30
	1 White Sucker	23.40
	1 Pumpkinseed Sunfish	4.82
	1 Pumpkinseed Sunfish	4.82
	1 Yellow Perch	21.90
	1 Yellow Perch	20.60

The results of pesticide analysis of a blueback herring and alewives from Carr's Island in the Merrimack River (see Figure 25) show that DDE and DDT were present in both the internal organs and in the body muscle tissue of those fish in measurable quantities (Table 49).

Data from the Massachusetts Division of Fisheries and Game (1971, 72) for the Assabet River show trace amounts of PCB's in fish from the Assabet River near Concord. None was detected in 1971 in five bluegills from the Concord area, however trace amounts of Aroclor 1248 were found in five bluegills from the same area in 1972.

There is some evidence that the Sudbury River fishery suffers from contamination by PCB's and mercury. A survey undertaken by the Massachusetts Division of Fisheries and Game (1971-1972) shows concentrations of Aroclor 1254 had a mean value of 7.05 ppm (dry weight) in five bluegills taken from the Sudbury River near Concord in 1972 and a level of 9.89 ppm (dry weight) in five bluegills taken from the same area in 1971. These levels are above the Environmental Protection Agency (1973) tissue concentration maximum of 0.5 ppb. Mercury levels of 4.4185 and 2.6479 ppm (net weight) were found in 13 largemouth bass and 19 yellow perch, respectively taken from the Framingham reservoir on the Sudbury River in 1971 (Massachusetts Division of Fisheries and Game (1971). These values are far above the EPA (1973)

TABLE 49. PESTICIDE ANALYSIS OF FINFISH SAMPLES TAKEN AT CARR'S ISLAND, SALISBURY, MERRIMACK RIVER ESTUARY, 1964

(Jerome, et. al., 1965)

DATE COLLECTED	SOURCE OF SAMPLE	DIELDRIN** OR DDE (ppm) (LBW)*	DDT (ppm) (LBW)
July 7	Intestine (*Alosa pseudoharengus*)	10.000	10.000
July 7	Body Muscle (*Alosa pseudoharengus*)	5.900	5.800
July 7	Intestine (*Alosa aestivalis*)	0.260	0.800
July 7	Body Muscle (*Alosa aestivalis*)	4.500	3.400

* (LBW): Live Body Weight

** Dieldrin-DDE: Not separable by method used standard of 0.5 ppm.

PCB levels found in five bluegills (1971) and five mummichogs (1972) by the Massachusetts Division of Fisheries and Game in the Concord River at Concord were above EPA (1973) standards. In bluegills the level was 6.90 ppm (dry weight) of Aroclor 1254, while 5.98 ppm (dry weight) Aroclor 1254 was found in the mummichogs. These PCB levels are similar to those found in the Sudbury River. Chlorinated hydrocarbon pesticide residues in fish from the Concord River have generally declined since 1965 (Table 50) (Lyman, Noyes, and Heeley, in press).

TABLE 50. CONCENTRATIONS OF PESTICIDES IN FISH TISSUE FROM THE CONCORD RIVER - 1972[1]

YEAR	NO.	SPECIES	DDT AND METABOLITES (ppm dry weight)	DIELDRIN (ppm dry weight)
1965	1	Yellow perch	9.10	
1965	3	Pumpkinseed	4.65	
1966	5	Golden shiner	9.45	
1967	5	Golden shiner	4.24	
1967	5	Yellow perch	4.06	
1968	5	Yellow perch	5.50	1.68
1970	5	Bluegill	0.93	17.54
1971	5	Bluegill	1.68	1.34
1972	5	Bluegill	1.59	17.66

[1] From Lyman, Noyes, and Heeley, (in press).

In summary, the Massachusetts section of the Merrimack River, because of its pollution load, supports a fishery deficient in desirable species. The SUASCO (Sudbury, Assabet, and Concord) tributary system, although supporting a fishery of higher diversity, is also contaminated by toxic materials (e.g. mercury and PCB's) and thus is of marginal value to the angler, and in some cases constitutes a health hazard. Of the remaining three tributaries, only the Squannacook is probably unaffected by toxic materials. In order to improve the quality of the Merrimack Riber Basin fishery, concentrations of toxic materials and direct and indirect sources of oxygen demand (BOD, COD, and nutrients) must be reduced in wastewater prior to its introduction into the aquatic system.

The anadromous fish restoration program introduces a unique area of concern. The states of Massachusetts, New Hampshire, the United States Bureau of Sport Fisheries, and the U. S. Bureau of Commercial Fisheries are cooperating in an effort to re-establish populations of Atlantic salmon and American shad in the Merrimack River. The financial benefits acruing from the success of this program would be enormous. Under optimum conditions, the expected annual run of American shad and Atlantic salmon might comprise as many as 1,000,000 fish and 11,000 fish respectively. Such runs would yield approximately 200,000 shad, and 1,650 to 2,750 Atlantic salmon, resulting in an economic gain of $1,000,000 for the American shad, and between $198,000 and $330,000 for the Atlantic salmon (personal communication, R. W. Dyer, 1974). As indicated by earlier discussions, removal of physical barriers may not be sufficient to insure the total success of this endeavor, as existing water quality may not be sufficient for a viable anadromous fishery.

Of the two species to be re-introduced, the Atlantic salmon appears to be the more sensitive to lowered water quality. In North America, salmon enter freshwater streams from the ocean to spawn from April through October, the exact timing being dependent on the river. In the Merrimack River, it is believed that the main spawning run would occur in the spring (June) during periods of reasonably high discharge (Bigelow and Schroeder, 1953). Little, if any, actual spawning activities would take place in the Massachusetts section of the river, such activities being almost entirely confined to the New Hampshire headwaters. Juveniles (two years old) would enter the sea following a downstream movement which occurs during a receding spring or early summer freshet when water temperatures are still cool (Technical Committee for Fisheries Management, 1971).

It is apparent from the literature that the Atlantic salmon does not have to be exposed to lethal levels of pollutants in order to inhibit normal spawning movements. Elson and Kerswill (1966), and Elson (1967) working in several New Brunswick streams established the toxic effects of DDT on immature Atlantic salmon. Elson (1967) also noted behavioral modifications related to DDT exposure in the form of Atlantic salmon parr and ripe males actually leaving streams during the fall months following spraying activities. Similar avoidance reactions have been noted for low concentrations of pentachlorophenol and cresote (Zitko *et al.*, 1969), and copper and zinc (Elson, *et al.*, 1971). Elson *et al.*, (1970) and Stasko (1971) working in the Miramichi estuary (New Brunswick) found that Atlantic salmon avoided pulpmill waste discharge, and swam more slowly through areas of pollution. Sprague and Drury (1969) noted avoidance of chlorine at concentrations of 0.01 ppm, while Sutterlin, *et al.*, (1971) concluded that surfactants interfered with chemoreception and consequently with migration and sensing of pollutants.

From the above brief discussion it can be noted that water quality conditions in the Merrimack River, as they relate to fish populations, must be evaluated in terms of both resident and anadromous species and lethal and sublethal effects which may negate a viable fishery.

7. Assumptions and Critical Information

a) WASTEWATER COMPOSITION

Composition of proposed secondary-treated and advanced-treated wastewaters for the Merrimack River Basin in Massachusetts including a comparison with Environmental Protection Agency (EPA) criteria for aquatic, marine and estuarine life and State requirements for class B waters is presented in Table 51. Those parameters with negative impact potential will be discussed below in detail.

1) NITROGEN COMPOUNDS

Although it is well known that nitrogen compounds are important algal nutrients, neither the Commonwealth of Massachusetts Water Resources Commission (1968) nor the Environmental Protection Agency (1973) recommend acceptable levels for natural waters (aquatic life standards).

Various authors, however, have recommended limits of inorganic nitrogen to prevent nuisance algal blooms. Sawyer (1970) recommended limits of inorganic nitrogen to 0.35 ppm after a study of the Occoquam Reservoir. MacKenthun (1965) cited data indicating upper limits of inorganic nitrogen at 0.3 ppm at the start of the growing season to prevent algal blooms. Jaworski *et al.* (1969), reviewing historical data for the upper Potomac estuary, states that at inorganic nitrogen concentrations of 0.5 ppm excessive algal blooms will occur. Brehmer and Haltiwanger (1966) indicate that nitrogen appears to be the rate limiting nutrient in the James River estuary. These values suggest that levels of no more than 0.3 ppm inorganic nitrogen should be permitted in

TABLE 51. COMPARISONS OF SECONDARY AND ADVANCED WASTEWATER EFFLUENT CONSTITUENTS TO ENVIRONMENTAL CRITERIA

(concentrations in ppm, 96-hr. LC_{50} refers to most sensitive important species present)

	SECONDARY[1]	AWT[2]	EPA (AQUATIC LIFE)[3]	EPA (MARINE AND ESTUARINE LIFE)[3]	COMMONWEALTH OF MASSACHUSETTS CLASS B WATERS[4]
B.O.D.	30	1.0	N.A.	N.A.	N.A.
C.O.D.	70	20.0	N.A.	N.A.	N.A.
Suspended Solids	30	1.0	N.A.	N.A.	N.A.
pH (units)	7.0	6-8.5	6.0-9.0	6.5-8.5	6.5-8.0
Total N	20	2.0	N.A.	N.A.	N.A.
Organic (as N)	2.0	0.5	N.A.	N.A.	N.A.
NH_3	10.0	0.5	1/20 96-hr LC_{50} ≤ 0.02	1/10 96-hr LC_{50} ≤ 0.4	0.5
NO_2	0.0	N.P.	N.A.	N.A.	N.A.
NO_3	8.0	1.0	N.A.	N.A.	N.A.
Total P	10-13	N.A.	N.A.	N.A.	N.A.
Total Phosphates (as P)	N.A.	.05	N.A.	N.A.	0.05
Phenols	0.3	?	1/20 96-hr LC_{50} ≤ 0.1	N.A.	.001

Continued

TABLE 51. (Continued)

	SECONDARY[1]	AWT[2]	EPA (AQUATIC LIFE)[3]	EPA (MARINE AND ESTUARINE LIFE)[3]	COMMONWEALTH OF MASSACHUSETTS CLASS B WATERS[4]
Be	N.P.	N.P.	N.A.	1/100 96-hr LC_{50} $\leq$ 1.5	N.E.
Ca	?	?	N.A.	N.A.	N.E.
Cd	0.1	?	.03 (Hard) .004 (soft) .0004 (salmonids)	1/100 96-hr LC_{50} $\leq$ 0.1	N.E.
Co	N.P.	N.P.	N.A.	N.A.	N.E.
Cr	0.2	?	N.A.	1/100 96-hr LC_{50} $\leq$ .1	N.E.
Cu	0.1	?	1/10 96-hr LC_{50}	1/100 96-hr LC_{50} $\leq$ .05	N.E.
Fe	0.1	?	N.A.	0.3	N.E.
Hg	0.005	?	max. .0002 max. av .00005 body .0005	1/100 96-hr LC_{50} $\leq$.001 not to be intentionally discharged	N.E.
K	?	?	N.A.	N.A.	N.E.
Mg	?	?	N.A.	N.A.	N.E.
Mn	0.2	?	N.A.	1/50 96-hr LC_{50} $\leq$ 0.1	N.E.

Continued

TABLE 51. (Continued)

	SECONDARY[1]	AWT[2]	EPA (AQUATIC LIFE)[3]	EPA (MARINE AND ESTUARINE LIFE)[3]	COMMONWEALTH OF MASSACHUSETTS CLASS B WATERS[4]
Dieldrin	?	?	0.005	N.A.	N.E.
Chlordane	?	?	0.04	N.A.	N.E.
Endosulfan	?	?	0.003	N.A.	N.E.
Endrin	?	?	0.002	N.A.	N.E.
Heptachlor	?	?	0.01	N.A.	N.E.
Lindane	?	?	0.02	N.A.	N.E.
Methoxychlor	?	?	0.005	N.A.	N.E.
Toxaphene	?	?	0.01	N.A.	N.E.
Pesticides (General)	?	?	1/100 96-hr. LC_{50}	1/100 96-hr. LC_{50}	N.E.
INORGANIC					
Al	?	?	N.A.	1/100 LC_{50} 1.5	N.E.
Ag	?	?	N.A.	1/20 96-hr LC_{50} $\leq$ .0005	N.E.
As	?	?	N.A.	1/100 96-hr LC_{50} < .05	N.E.
B	0.7	?	N.A.	1/10 96-hr LC_{50}	N.E.
Ba	N.P.	N.A.	N.A.	1/20 96-hr LC_{50} $\leq$ 1.0	N.E.

Continued

TABLE 51. (Continued)

	SECONDARY[1]	AWT[2]	EPA (AQUATIC LIFE)[3]	EPA (MARINE AND ESTUARINE LIFE)[3]	COMMONWEALTH OF MASSACHUSETTS CLASS B WATERS[4]
Chlorine	?	?	.003 0.05 for 30 min. in 24 hrs.	1/10 96-hr LC_{50} ≤ 0.01	N.E.
MBAS	?	?	1/20 96-hr LC_{50} ≤ 0.2	N.A.	N.E.
F^-	?	?		1/10 96-hr LC_{50} ≤ 1.5	N.E.
CN^-	?	?	1/20 96-hr LC_{50} ≤ 0.005	1/10 96-hr LC_{50} ≤ 0.01	N.E.
Oil and Grease	?	?	1/20 96-hr LC_{50} never in ≥ 1000 sediment	no visual or olfactory sense or threat to life	none
H_2S	?	?	.002	1/10 96-hr LC_{50} ≤ 0.01	N.E.
PCB's	?	?	.000002 .0005 burden	N.A.	N.E.
Phthalate Esters	?	?	.0003	N.A.	N.E.
Sulfate	125	?	N.A.	N.A.	N.E.
Chlorides	100		N.A.	N.A.	N.E.
Aldrin	?	?	0.01	N.A.	N.E.
DDT	?	?	0.002	N.A.	N.E.
TDE	?	?	0.006	N.A.	N.E.

Continued

TABLE 51. (Continued)

	SECONDARY[1]	AWT[2]	EPA (AQUATIC LIFE)[3]	EPA (MARINE AND ESTUARINE LIFE)[3]	COMMONWEALTH OF MASSACHUSETTS CLASS B WATERS[4]
Mo	N.P.	N.P.	N.A.	1/20 96-hr LC_{50}	N.E.
Na	S.A.R = 4.6	?	1/50 96-hr LC_{50}	N.A.	N.E.
Ni	0.2	?	N.A.	1/50 96-hr LC_{50} $\leq$ 0.1	N.E.
Pb	0.1	N.A.	0.03	1/50 96-hr LC_{50} max 1/100 96-hr LC_{50} max av $\leq$ .05	N.E.
Sb	N.P.	N.A.	N.A.	1/50 96-hr LC_{50} $\leq$ 0.2	N.E.
Si	?	?	N.A.	N.A.	N.E.
Sn	N.P.	N.A.	N.A.	N.A.	N.E.
Se	N.P.	N.A.	N.A.	1/100 96-hr LC_{50} $\leq$ .01	N.E.
V	?	?	N.A.	1/20 96-hr LC_{50}	N.E.

Continued

TABLE 51. (Continued)

	SECONDARY[1]	AWT[2]	EPA (AQUATIC LIFE)[3]	EPA (MARINE AND ESTUARINE LIFE)[3]	COMMONWEALTH OF MASSACHUSETTS CLASS B WATERS[4]
Y	N.P.	N.A.	N.A.	N.A.	N.E.
Zn	0.2	?	5/1000 96-hr LC_{50}	1/100 96-hr LC_{50} ≤ 0.1	N.E.

Notes: ? not prescribed but likely to occur
N.P. probably not present
N.E. none in concentrations or combinations which would be harmful or offensive to humans, or harmful to animal or aquatic life
N.A. not ascertained

[1] As prescribed by U.S.A.C.E.

[2] As prescribed by Anderson Nichols

[3] Environmental Protection Agency (1973)

[4] Commonwealth of Massachusetts, Division of Water Pollution

[5] Normandeau Associates (1973, 1974)

fresh and estuarine waters to minimize the risk of nuisance algal blooms.

2) PHOSPHOROUS COMPOUNDS

The Commonwealth of Massachusetts Water Resources Commission (1968) states that class B and C waters should not contain more than 0.05 ppm total phosphate (as P) during any monthly sampling period. The Environmental Protection Agency (1973) has not set any criteria for phosphorous compounds. The National Technical Advisory Committee (1968), however, suggests as a guideline, that the concentration of total phosphates should not be increased to levels exceeding 0.1 ppm in flowing streams or 0.05 ppm where streams enter lakes or reservoirs. Various authors have suggested similar levels. Sawyer (1970) recommends a level of 0.02 ppm total phosphates. MacKenthun (1965) suggests a limit of 0.01 ppm at the start of the growing season.

The consensus of various experts is that the total inorganic phosphorous content of limnetic surface waters should be between 0.1 and 0.01 ppm if nuisance algal blooms are to be prevented. It should be noted that impounded waters are more susceptible to nuisance bloom conditions than freely flowing systems. Since the Merrimack River and many of its tributaries are at least partially impounded, a range of 0.05 to 0.07 ppm total inorganic phosphorous was arbitrarily chosen as a reference level for the evaluative purpose of this analysis.

The Commonwealth of Massachusetts Water Resources Commission (1971) states that total phosphate concentrations in coastal and marine waters classified as SA, SB, and SC waters should not exceed an average of 0.07 ppm (as P) during any monthly sampling period. The Environmental Protection Agency (1973) has not addressed itself to the question of nutrient associated problems of phosphorous compounds in the marine environment, but rather to the toxic levels of phosphorous metal. The National Technical Advisory Committee (1968) states that the naturally occurring atomic ratio of NO_3 - N to PO_4 - P in a body of water should be maintained. Similarly, the ratio of inorganic phosphorous (ortho-phosphate) to total phosphorous (the sum of inorganic phosphorous, dissolved organic phosphorous, and particulate phosphorous) should be maintained as it occurs naturally. In justifying this statement, it was pointed out that imbalanaces have been shown to bring about a change in the natural diversity of the desirable organisms and to reduce productivity.

Certain values for keeping algal production below nuisance levels have been suggested in the literature. Pritchard (1969), in a study of the Chesapeake Bay and its tributaries, suggested that if total inorganic phosphorous concentrations in estuarine waters were kept below 0.03 ppm, biologically healthy conditions would be maintained. Jaworski *et al.* (1969), reviewing historical data for the upper Potomac estuary, indicated that should concentrations of inorganic phosphorous reach approximately 0.1 ppm nuisance algal growth would result. Jaworski *et al.* (1972) have suggested that a level of .025 to 0.1 ppm inorganic phosphorous be set for evaluating marine and estuarine waters. This range is in agreement with the 0.07 ppm total phosphate set by the Massachusetts Water Resources Commission classification scheme discussed previously.

3) AMMONIA

The toxicity of ammonia solutions is pH dependent. In most natural waters conditions are such that ammonium ions (NH_4+) dominate. In alkaline waters high concentrations of un-ionized ammonia as undissociated ammonium hydroxide increases the toxicity of ammonia solutions (NAS, 1972; NTAC, 1968). In sewage polluted streams up to one half of the nitrogen in the sewage may be in the free ammonia form (Winslow and Phelps, 1906 in Ellis, 1937). Acute toxicity data compiled for several fish species show a mean 96-hour LC_{50} ranging from 0.29 to 0.89 ppm (NAS, 1972). The EPA (1973) recommends a level in fresh water of 0.02 ppm which is approximately one-half the no effect level for rainbow trout (Lloyd and Orr, 1969).

Most available data on the toxic properties of ammonia solutions are for freshwater. Doudoroff and Katz (1961) feel that because of sea water's slightly higher alkalinity and larger proportion on un-ionized ammonium hydroxide, ammonia may be more toxic in sea water than in fresh. The EPA (1973) recommends that the level of ammonia in sea water not exceed 0.4 ppm.

4) DISSOLVED OXYGEN

It has been found that the relationship of dissolved oxygen to aquatic life is extremely significant. Any reduction of dissolved oxygen can reduce the efficiency of oxygen uptake by aquatic animals, and hence reduce their ability to meet the demands of their environment. Evidently there is no concentration level or percentage of saturation to which the dissolved oxygen content of natural waters can be reduced without causing or risking some adverse effects on the reproduction, growth, and consequently the production of fishes inhabiting those waters (NAS, 1972). The Environmental Protection Agency (1973) has adopted the following criteria for the protection of aquatic life:

°C	Oxygen Levels for Complete Saturation (ppm)	Minimum Levels for Protection of Salmonid Spawning (ppm)	Minimum Levels for Protection of Aquatic Life (ppm)
36.0	7	6.4	5.8
27.5	8	7.1	5.8
21.0	9	7.7	6.2
16.0	10	8.2	6.5
7.7	12	8.9	6.8
1.5	14	9.3	6.8

Under extreme conditions for short periods of time (not more than 24 hours), a minimum limit of 4 ppm is acceptable for waters above 31°C (87.8°F).

The oxygen requirements of marine organisms have not been as extensively investigated as those of freshwater organisms. It is known that soft-shell clam larvae cannot tolerate oxygen levels below 4.0 ppm, and additional experimentation indicates that it is essential to consider responses of developing eggs and larvae of marine species, as well as the juvenile and adult individuals (Thiede, *et al.*, 1969; Morrison, 1971).

The EPA (1973) recommends a minimum acceptable level of dissolved oxygen in marine and estuarine waters of 6.0 ppm, except when temporary natural phenomena cause this value to be decreased. Dissolved oxygen levels below 4.0 ppm in marine or estuarine waters are unacceptable (EPA, 1973).

5) CHLORINE

The toxicity of chlorine in water to aquatic life depends upon the concentration of residual chlorine and the relative amounts of free chlorine and chloramines (Brungs, 1972). Apparently, the toxicity of free chlorine in water is on the same order as that of chloramines, and the toxicity of chlorine can generally be estimated from a measure of residual chlorine (Doudoroff and Katz, 1950; Merkins, 1958). LC_{50} chlorine levels for fish are indicated below:

TIME	CONCENTRATION (ppm)	AUTHOR
7 days	0.008	Merkins, 1958
96 hours	0.05-0.19	Zillich, 1972
96 hours	0.23	Basch *et al.*, 1971

In chronic exposure tests, fecundity in fathead minnows was reduced by 0.043 ppm total chloramines. Survival and reproduction were reduced in *Gammarus* by exposure to 0.04-0.0034 ppm (Arthur and Eaton, in press EPA, 1973). Apparently, aquatic organisms can tolerate short term exposure to higher levels of chlorine without harmful effects; however, chronic exposure to concentrations in excess of 0.003 ppm can cause chronic toxic effects (EPA, 1973). The following criteria for residual chlorine are proposed by the EPA (1973):

1) Maximum acceptable level --- 0.003 ppm

2) Maximum concentration of 0.05 ppm for $\leq$ 30 minutes in a 24-hour period.

Chlorine is one of the few elements which has been experimentally demonstrated to have a specific toxicity to marine organisms (EPA, 1973). Studies of irritant responses of marine fishes to chlorine showed a slight activity at 1.0 ppm and violent irritant activity at 10 ppm (Moore, 1951). Sprague and Drury (1969) found that salmonid fish avoided chlorine concentrations as low as 0.01 ppm but were not as successful in avoiding lethal concentrations (0.1 ppm). Oysters have been found to be sensitive to chlorine at concentrations of 0.01-0.05 ppm and react by reducing pumping activity. At Cl^- concentrations of 1.0 ppm effective pumping could not be maintained (Galstoff, 1946). Adult mussels (*Mytilus edulis*) were killed by exposure to 2.5 ppm of chlorine within 5 days (Gentile, 1972). Two species of copepods, *Acartia tonsa* and *Eurytemora affinis,* showed LC_{50} values of 36 and 120 seconds respectively at a chlorine concentration of 10 ppm (Gentile, 1972).

The EPA (1973) recommends the following chlorine levels for marine and estuarine waters.

1) Maximum concentration 1/10 96-hour LC_{50} for most sensitive/important organisms present.

2) Never greater than 0.01 ppm.

6) PHENOLS

Phenols and phenolic wastes are derived from petroleum, coke, and chemical industries; wood distillation; and domestic and animal wastes. Many phenolic compounds are more toxic than pure phenol; their toxicity varying with the combinations and general nature of total wastes. The chronic effects of phenolics have not been documented adequately to prescribe safe levels for fish (EPA, 1973). However, phenolics affect the taste of fish at levels that do not appear to adversely affect fish physiology (NAS, 1972). Mixed wastes often have more objectionable effects than pure materials. Following are some examples of phenolic compound concentrations which affect taste:

2, 4 dichlorophenol	0.001-0.05 mg/l
1 methyl, 6 chlorophenol	0.003 mg/l
p chlorophenol	0.01-0.06 mg/l
pure phenol	1-10 mg/l

7) HEAVY METALS

Current information regarding the biological role and impact of the various toxic metals and metallic salts is extensively reviewed in a recent EPA publication (Proposed Criteria for Water Quality Volume I, 1973). The following discussion draws heavily from the contents of this review.

Cadmium is an extremely dangerous cumulative toxicant, causing insidious, progressive chronic poisoning in mammals (Nilsson, 1970), fish, and probably other animals because the metal is not excreted (see NAS, 1972). The eggs and larvae of fish are apparently more sensitive than adult fish to poisoning by cadmium, and crustaceans are evidently more sensitive than fish eggs and larvae (see NAS, 1972). The safe levels of cadmium for fathead minnows (Pickering and Gast, 1973) and bluegills in hard water are between 0.06 and 0.03 ppm, and safe levels for coho salmon fry have been reported between 0.004 to 0.001 ppm in soft water (see NAS, 1972).[1] Concentrations of 0.0005 ppm were observed to reduce reproduction of *Daphnia magna* in one generation exposures lasting three weeks (see NAS, 1972).

The EPA (1973) gives the following for cadmium in freshwater:

1) Hard water (> 100 ppm $CaCO_3$) 0.03 ppm

2) Soft water[1] ($\leq$ 100 ppm $CaCO_3$) 0.004 ppm

In waters where crustacea and the eggs and larvae of salmonids develop, recommended levels are 0.003 and 0.0004 ppm for hard and soft water, respectively.

Concern exists that cadmium may enter the diet, like mercury, through seafood. Cadmium, also like mercury, could form organic compounds which might be highly toxic or lead to mutagenic or teratogenic effects. American oysters (*Crassostrea virginica*) have demonstrated an LD_{50} response to 0.2 ppm after 8 weeks exposure, and to 0.1 ppm after 15 weeks exposure (NTAC, 1968).

Cadmium also acts synergistically with other metals. It inhibits shell growth in oysters (Pringle, *et al.*, 1968), and low doses of cadmium (0.03 ppm) in combination with zinc (0.15 ppm) will kill chinook salmon fry (Houblou,

[1] Surface waters in the Merrimack River Basin are considered soft.

1954). Killifish (*Fundulus heteroclitus)* exposed to 50 ppm cadmium showed pathological changes in the intestinal tract after a 1-hour exposure, and in the kidney after 12 hours (Gardner and Yevich, 1970). Copper and zinc, when present at 1 ppm more, substantially increase the toxicity of cadmium (LaRoche, 1972). Cadmium is concentrated by marine organisms, particularly molluscs, which accumulate cadmium in calcareous tissues and in the viscera (Brooks and Rumbsby, 1965). A concentration factor of 1000 for cadmium in fish muscle has been reported (Lowman, *et al.*, 1971) as have concentration factors of 3000 in marine plants, and up to 29,600 in certain marine animals (NTAC, 1968).

The EPA (1973) has set the following criteria for cadmium in marine and estuarine waters:

1) 1/100 96-hour LC_{50} for most sensitive/important organisms

2) never > 0.01 ppm.

The toxicity of chromium for aquatic life varies widely with biotic and abiotic variables (McKee and Wolf, 1963). Recent data indicate that some lower members of the food web are more sensitive to chromium than are fish. The reported lethal limits of chromium for fish are 17 and 118 ppm as compared to 0.05 ppm for macroinvertebrates, and 0.032 to 6.4 ppm for algae (NAS, 1972). The EPA (1973) states that the maximum acceptable total chromium concentration for the well being of aquatic life is 0.05 ppm.

Chromium concentrations in seawater generally have been reported between 0.04 and 0.4 ppm (NAS, 1972; Goldberg, 1972), but concentration factors of 1,600 in benthic algae, 2,300 in phytoplankton, 1,900 in zooplankton, 440 in soft parts of molluscs, 100 in crustacean muscle, and 70 in fish muscle have been reported (Lowman, *et al.*, 1971). Chromium threshold toxicity levels of 1.0 ppm for the polychaete *Nereis virens* and 20 ppm for the crab *Carcinus maenus* have been reported (Raymond and Shields, 1964).

The EPA (1973) gives the permissible level of chromium in marine and estuarine waters as follows:

1) 1/100 96-hour LC_{50} for the most sensitive/important organisms.

2) never > 0.1 ppm.

The toxicity of copper varies with the chemical characteristics of the water and with the species of test organism (McKee and Wolf, 1963). Concentrations of 0.006 ppm in soft water are thought to be safe for the reproduction and growth of *Daphnia magna* and fish; in hard water, levels of 0.033 are apparently safe (NAS, 1972). The EPA states that the limit be set at 1/10 96-hour LC_{50} for the most sensitive important species. In the soft water of the Merrimack River this would be approximately 0.006 ppm.

Copper is present in seawater in concentrations ranging from 0.001 to 0.025 ppm; however, values are generally less than 0.003 ppm (Oregon State University, 1971). In small amounts, copper is nonlethal to aquatic organisms; in fact, it is essential for some respiratory pigments (Wilber, 1969); however, it is accumulated by marine organisms, with concentration factors of 30,000 reported in phytoplankton, 5,000 in the soft tissues of molluscs and 1,000 in fish muscle (Lowman, *et al.*, 1971; McKee and Wolf, 1963) Copper is toxic to invertebrates. Molluscs in particular show great sensitivity to copper compounds. The mussel *Mytilus edulis* showed 100 percent mortality at 0.14 ppm copper within 24 hours (Clarke, 1947). Copper is toxic to oysters at low concentrations (Wilber, 1969; Galstoff, 1932; Fugiya, 1960), although toxicity apparently varies between species (Reish, 1964). Oysters exposed to concentrations of copper as low as 0.13 ppm turn green in about 21 days (Galstoff, 1932), and although such concentrations of copper are neither lethal to the oysters nor harmful to man, green oysters are unmarketable because of their appearance. Thus, in the vicinity of oyster grounds, copper should not be introduced into areas where shellfish may become contaminated. Other marine invertebrates and plants have also shown a sensitivity to copper compounds. The copepod *Acartia clausi* when exposed to a dose of 0.5 ppm copper, showed an LD_{50} within 13 hours (Doudoroff, 1957). The tubeworm *Spirobis lamellosa,* also exposed to a dose of 0.5 ppm copper, had an LD_{50} within 2 hours (Wisely and Blick, 1967).

Finally, in studies of the sublethal effects of copper compounds results have shown that Atlantic salmon *(Salmo salar)* will avoid copper concentrations as low as 0.0024 ppm, indicating that an extremely sensitive copper-sensing mechanism is present in these fish (Sprague, 1965; 1971; Saunders and Sprague, 1967). The EPA (1973) states that in marine and estuarine waters the copper concentration should never exceed 1/100 96-hour LC_{50} of the most sensitive/important species and should never exceed 0.05 ppm.

The toxicity of lead in water varies with its solubility, which is a function of the hardness of the water. In soft waters (such as those found in the Merrimack River) lead has a solubility of 0.5 ppm, whereas in hard water the solubility is only 0.003 ppm (NAS, 1972). The effect of hardness upon the toxicity of lead was demonstrated by acute toxicity tests on several species of fish in waters of varying hardness. The 96-hour LC_{50} values in soft waters (20-45 ppm $CaCO_3$) were 1.0 ppm for rainbow trout (Brown, 1968), 4.0-5.0 mg/l for brook trout and 5.0-7.0 ppm for fathead minnows (Pickering and Henderson, 1966; NAS, 1972). In hard waters 96-hour LC_{50} values were 442 ppm for brook trout and 482 ppm for fathead minnows (Pickering and Henderson, 1966). Preliminary information on chronic toxicity of lead to rainbow and brook trout indicated detrimental effects at 0.10 ppm in soft water (NAS, 1972). The safe level for *Daphnia* has been reported as 0.03 ppm, and it has been suggested that this is also the safe level for fish (NAS, 1972). The EPA (1973) states that concentrations of lead in freshwater systems should never exceed 0.03 ppm.

Certain marine plants have the ability to concentrate lead up to 40,000 times and certain marine animals up to 2,000 times (Calabrese, *et al.*, 1973). Very few experiments have been performed on the biological effects of lead on marine organisms. It has been found that lobsters died within 20 days when held in leadlined tanks (Wilder, 1952); the TLM for oysters (*Crassostrea virginica)*, was found to be 0.5 ppm lead when exposed for 12 weeks (NTAC, 1968); and the 48-hour LC_{50} for *Crassostrea virginica* eggs was found to be 2.45 ppm (Calabrese, *et al.*, The EPA (1973) states that the lead concentration in marine and estuarine waters should never exceed a maximum of 1/50 96-hour LC_{50} of the most sensitive/important species and never exceed a maximum average concentration of 1/100 96-hour LC_{50} of the most sensitive/important species. Under no circumstances should the lead concentration exceed 0.05 ppm.

Manganese apparently has varying effects on lower trophic levels of aquatic organisms. Manganese concentrations of .005 ppm have a toxic effect on certain freshwater algae (Guseva, 1939), whereas 0.0005 ppm manganese (a decrease of only one order of magnitude) when added to marine diatom and flagellate cultures stimulated both their growth and reproduction rate (Harvey, 1947). Further, in studies on the uptake of radionuclides in the area of the Pacific testing grounds at Bikini and Eniwetok, it was found that the radionuclide Mn 54 was concentrated as much as 4,000 times in phytoplankton and 12,000 times in the soft tissues of molluscs (Lowman, 1960; 1971).

The EPA (1973) states that the manganese concentration in marine waters should never exceed 1/50 96-hour LC_{50} for the most sensitive/important species and under no circumstances exceed 0.1 ppm.

The main body of available information is on organic compounds of mercury which are generally more dangerous to aquatic life and man. Since inorganic mercury is changed by organisms in nature to the organic forms the same limits are prescribed by the EPA (1973) for both forms.

Mercury is a dangerous, cumulative toxicant which enters the bodies of aquatic organisms directly from the water and through food chains. Although methyl mercury is the form of mercury of primary concern as regards toxicity, the ability of certain microbes to synthesize methylmercury from the inorganic form, renders all mercury in waterways potentially dangerous. Since mercury is biologically concentrated through the food web, levels of protection in the aquatic environment must be such that final consumers, including man, are afforded adequate protection. Freshwater phytoplankton, macrophytes and fish are capable of biologically magnifying mercury concentrations from water 1,000 times (Chapman, Fisher and Pratt, 1966). Concentration factors of 5,000 from water to pike have been reported (Johnels, *et al.*, 1967) and factors of 10,000 or more have been reported from water to brook trout (NAS, 1972) and to some invertebrates (Hannerz, 1968). The chronic effects of mercury upon reproduction and growth of fish are not well known. The lowest level which has resulted in the death of fish is 0.0002 ppm, which killed fathead minnows exposed for 6 weeks (NAS, 1972). A level of 0.0001 ppm decreased photosynthesis and growth of marine algae and some freshwater phytoplankton (Harriss, White, and MacFarlane, 1970). Exposure of fish for a period of three months to concentrations of 0.00005 ppm of mercury in water resulted in concentrations of 0.5 ppm in the fish (NAS, 1972). This is the maximum Food and Drug Administration guideline level for edible portions. In an effort to maintain mercury concentrations in fish below 0.5 ppm the EPA (1973) has set the following limits for the aquatic environment.

1) Maximum of 0.0002 ppm

2) Maximum average of 0.00005 ppm

3) **Never** to be intentionally discharged to natural waters.

The behavior of mercury in the marine environment is not completely understood. Organo-mercurials are more highly concentrated by organisms than are inorganic mercury (Chapman, Fisher and Pratt, 1966) compounds. In addition to being biologically concentrated to a greater degree than inorganic mercury compounds, organo-mercurials are much more toxic than inorganic mercury to marine organisms (Jensen, Johansson, and Olsson, 1970). In many species of marine phytoplankton photosynthetic activity has been shown to be inhibited by a variety of mercury compounds (European Inland Fisheries Advisory Commission, 1965). Vertebrate marine organisms have also experienced marked detrimental effects from mercury compounds. Concentration factors have been reported to range from 200 for marine diatoms (Fry, 1947) to 10,000 for marine teleosts (Fry, 1964). Further, the acute toxicity of mercury to invertebrate marine organisms is high. Bivalve larvae were killed by 0.020 ppm of mercuric chloride (Fry, 1970); copepods (*Acartia clausi)* were killed in 2.5 hours by 0.050 ppm (EPA 1973); 1.0 ppm of mercuric chloride was lethal to adult barnacles *(Balanus balanoides)* within 48 hours (Doudoroff, Leduc, and Schneider, 1966); and the LD_{50} for tubeworm larvae *(Spirorbis lamellosa)* was found to be 0.14 ppm in 2 hours (Lovett, 1957).

The EPA (1973) has set the maximum allowable concentration of mercury in marine waters at 1/100 96-hour LC_{50} for the most sensitive/important species, and it is never to exceed 0.001 ppm.

<u>Nickel</u> as a pure metal does not constitute a serious water pollution problem; however, many of the salts of nickel are highly soluble in water and may present serious hazards to aquatic life (McKee and Wolf, 1963). The 96-hour LC_{50} of nickel for fathead minnows ranges from 5 ppm in soft water to 43 ppm in hard water (Pickering and Henderson, 1966). Chronic safe concentrations for fathead minnows in hard water have been reported as varying between 0.8 and 0.4 ppm, and in soft water levels of 0.030 ppm had no effect on *Daphnia magna* during a 3-week exposure (see NAS, 1972). The EPA states that 1/50 96-hour LC_{50} of the most sensitive/important species is the maximum allowable concentration of nickel in freshwater systems.

Marine toxicity data for nickel are limited. It is known, however, that nickel ions are toxic, particularly to plant life, and may have increased toxicity when in the presence of other metallic ions. Nickel is present in coastal and open ocean concentrations in the range 0.0001 - 0.0006 ppm, although the most common values are 0.002 - 0.003 ppm. Marine animals contain up to 0.4 ppm and marine plants contain up to 3.0 ppm (Schutz and Turekian, 1965). The lethal limit of nickel to sticklebacks has been reported as 0.8 ppm (Murdock, 1953); concentrations of 13.1 ppm were reported to cause a 50 percent photosynthesis reduction in giant kelp (*Macrocystis pyrifera)* in 96 hours (Clendenning and North, 1960); and a concentration of 1.54 mg/l was found to be the LC_{50} value for eggs of the oyster *(Crassostrea virginica)* (Calabrese, *et al.*, 1973).

The EPA (1973) states that in marine and estuarine waters the concentration of nickel should never exceed 1/50 96-hour LC_{50} of the most sensitive/important species and never exceed 0.1 ppm.

The acute lethal toxicity of zinc varies greatly with the hardness of the water, with the 96-hour LC_{50} for fathead minnows ranging from 0.87 ppm in soft water to 33 ppm in hard water (Pickering and Henderson, 1966). The lethal threshold also varies significantly between fish species, with bluegills more resistant than fathead minnows (NAS, 1972), and coarse fish more resistant than brook trout (Ball, 1967). Differences between acute and safe chronic concentrations of zinc on fathead minnows are great. In hard water, levels of 0.003 ppm had no effect on fathead minnow reproduction, while 0.18 ppm caused an 83 percent reduction in fecundity (Brungs, 1969). The EPA (1973) states that the zinc concentration in freshwater should never exceed 5/1000 96-hour LC_{50} of the most sensitive/important species.

The major concern with zinc compounds in marine waters is not one of acute toxicity, but rather of the long-term sub-lethal effects of the metallic compounds and complexes. There is some information on the former, but solid data on the latter are sparse. From an acute toxicity point of view, invertebrate marine animals seem to be the most sensitive organisms tested. Concentrations of zinc have been reported as high as 1,500 ppm in marine animals (EPA, 1973), and concentration factors for zinc have been noted as high as 100,000 times in certain shellfish (McKee and Wolf, 1963). The EPA (1973) allowed level of zinc in marine and estuarine waters is 1/100 96-hour LC_{50} of the most sensitive/important species and is never to exceed 0.1 ppm.

8) CYANIDES

Cyanides in water derive their toxicity primarily from undissociated hydrogen cyanide (HCN) rather than from the cyanide ion (CN^-). Since the dissociation of HCN in water to form H^+ and CN^- is pH dependent, the toxicity of cyanide varies greatly with pH. At a pH of 7.0 or below, less than 10 percent of the cyanide present is in the undissociated form; at a pH of 8.0, 6.7 percent; at a pH of 9, 42 percent; and at a pH of 10, 87 percent. In the Merrimack River and its tributaries, the pH is such that cyanide would remain in its undissociated, toxic form. A cyanide level as low as 0.01 ppm is known to have a pronounced, rapid, lasting effect on the swimming ability of salmon (NAS, 1972).

The EPA (1973) has set the permissible levels of cyanide as follows:

1) Freshwater (aquatic life)
   a. 1/20 96-hour LC_{50} of most sensitive/important species
   b. never > 0.005 ppm

2) Marine and estuarine (aquatic life)
   a. 1/10 96-hour LC_{50} of most sensitive/important species
   b. never > 0.01 ppm

9) POLYCHLORINATED BIPHENYLS

PCB's are highly cumulative, with accumulation factors up to 200,000 indicated by long term exposure of fish to low PCB concentrations (NAS, 1972). PCB residue levels of 0.5 ppm in whole salmon eggs have been suggested as the threshold for eggs mortality (Jensen, Johannson, Olsson, 1970). Such levels in eggs are associated with levels in the body tissue of 0.0025 to 0.005 ppm (NAS, 1972).

The EPA (1973) has set the following as the permissible PCB level in natural waters as follows:

1) Freshwater
   a. never > 0.000002 ppm
   b. never > 0.0005 ppm body burden

10) PHTHALATE ESTERS

Phthalate ester residues are highly cumulative in animal tissue and principally occur in natural waters exposed to industrial and heavily populated areas. Acute toxicity tests showed the 96-hour LC_{50} of *Daphnia magna* and four species of fish to range from 0.731 to 6.470 ppm (NAS, 1972). In chronic toxicity tests a concentration factor of 6,000 for *Daphnia magna* magna was reported (NAS, 1972).

The EPA (1973) has set the following as the permissible phthalate ester level for natural waters:

1) Freshwater never > 0.0003 ppm

11) SURFACTANTS

The primary toxic components of detergents is the linear alkylate sulfonates (LAS). Since 1965 these have been used to replace the less readily biodegradable alkylbenzene sulfonates (ABS). LAS is two to four times more toxic to aquatic life than ABS (Pickering, 1966). Various studies have shown that LAS is more toxic to invertebrates than vertebrates (Pickering, 1966; Pickering and Thatcher, 1970; Arthur, 1970; Hokanson and Smith, 1971).

The EPA (1973) has set the following as the permissible LAS concentration in natural waters:

1) Freshwater (aquatic life)
   a. 1/20 96-hour LC_{50} for most sensitive/important species
   b. never > 0.2 ppm

12) OILS

The toxicity of oils to aquatic life varies widely. Oils gain their toxic properties through both physical and chemical means (EPA, 1973). The level of oil in sewage effluent is generally quite small.

The EPA (1973) has set the following criteria for oil concentrations in the aquatic ecosystem:

1) Freshwater
   a. 1/20 96-hour LC_{50} most sensitive/important species
   b. concentration of hexane extractable fraction exclusive of elemental sulfur in air dried sediment is not to exceed 1000 ppm by weight
   c. no visible fibers on water surface

2) Marine and estuarine (aquatic life)
   a. no visible fibers
   b. no oily deposits
   c. no oily odor
   d. not to become an effective toxicant

13) <u>PESTICIDES</u>

Although these materials present a significant environmental hazard, they will not be discussed within the framework of water oriented waste treatment alternative evaluations since they enter the aquatic ecosystem primarily from sources other than domestic and industrial wastewater.

14) <u>ALUMINUM</u>

Aluminum is known to be biomagnified. Lowman, *et al.*, (1971) give concentration factors of 15,000 for benthic algae, 10,000 for phytoplankton and zooplankton, 9,000 in the soft parts of molluscs, 12,000 in crustacean muscle, and 10,000 in fish muscle. Except for some now conclusive research (Pulley, 1950; Wilder, 1952), specific work on the toxicity of aluminum is sparse. Aluminum hydroxide, however, is known to have an adverse effect on benthic communities.

The EPA (1973) has established the following criteria for aluminum levels in natural waters:

1) Marine and Estuarine (aquatic life)
   a. 1/100 96-hour LC_{50} most sensitive/important species
   b. never > 1.5 ppm

15) ARSENIC

Arsenic is normally present in sea water at concentrations of 0.002 to 0.003 ppm and tends to be accumulated by oysters and other molluscs (Sautet, 1964; Lowman, *et al.*, 1971) with concentrations of 100 ppm reported in shellfish (Willier, 1969). Arsenic is a cumulative poison with long term chronic effects on both aquatic organisms and mammalian species. A succession of small doses may add up to a final lethal dose (Buchanan, 1962).

The EPA (1973) has established the following permissible arsenic levels for natural waters:

1) Marine and Estuarine (aquatic life)
    a. 1/100 96-hour LC_{50} most sensitive/important species
    b. never > 0.05 ppm

16) IRON

In the marine environment, iron is most often present either in organic complexes or in the ferric form adsorbed on particulate matter. However, because of the slightly alkaline condition of sea water, much of the ferric form precipitates out (NAS, 1972). Thus, ferric hydroxide flocs may contaminate marine sediments and affect commercially important invertebrate species, such as oysters, clams, scallops, lobsters, crabs and shrimp. Although damage to aquatic organisms is known from the smothering and coating action of the flocs, the available evidence is only from fresh water experimentation (Southgate, 1948; Knight, 1901; Olson, 1941; Minkina, 1946; Bandt, 1946; ORSANCO, 1960).

The EPA (1973) has set the following maximum acceptable level for iron in natural waters:

1) Marine and Estuarine (aquatic life)
    a. never > 0.3 ppm

17) MAGNESIUM

Magnesium compounds are toxic to aquatic and marine life only at high concentrations [> 100 ppm (McKee and Wolf, 1963)]. Because of this it is not felt that this metal constitutes a serious environmental hazard in the Merrimack River or its tributary streams.

18) SILVER

Silver is toxic to marine organisms and has been found to be concentrated by marine organisms by factors ranging from 80 for marine algae to 1,000 for marine mammals (Oregon State University, 1971).

The EPA (1973) has set the following as the maximum permissible concentration of silver in natural waters:

1) Marine and Estuarine (aquatic life)
   a. 1/20 96-hour LC_{50} most sensitive important organisms
   b. never > 0.0005 ppm

19) SODIUM

Most sodium compounds are toxic to fresh water and marine organisms only at high concentrations [generally > 100 ppm (McKee and Wolf, 1963)]. An exception to this is sodium chromate which is highly toxic. Freeman and Fowler (1953) found that sodium chromate exhibited a 100-hour toxicity threshold toward *Daphnia magna* of 0.286 ppm at a pH of 7.3.

20) BORON

Available toxicity data for boron are for fresh-water organisms; however, since the toxicity of boron to aquatic organisms is slightly lower in hard water than in distilled water, it is anticipated that boric acid and borates would be less toxic to marine life than to fresh water organisms (NAS, 1972). The effect of boron on marine plants is uncertain (EPA, 1973). Since terrestrial plants are harmed by boron in excess of 1.0 ppm (Wilber, 1969), it is felt that special precautions should be taken to keep boron concentrations at natural levels in the vicinity of kelp, eel grass, and other seaweed beds.

The EPA (1973) has set the permissible level of boron in natural waters as follows.

1) marine and estuarine (aquatic life)
   a. 1/10 96-hour LC_{50} most sensitive important species

21) CHLORIDES

Hart *et al.*, (1945) cite data indicating that among U. S. waters supporting a good fish fauna, ordinarily the concentrations of chlorides is below 3 ppm in 5 percent of such waters. Adams (1940) found 400 ppm of chloride to be harmful to trout while bluegills tolerated up to 8100 to 10,500 ppm (Wood, 1957). Chlorinity is closely related to total salinity and its effects on osmosis. It is evident that freshwater fish cannot tolerate excessive increases in salinity; and most saltwater fish are vulnerable to waters of low salinity. Chlorides discharged from sewage treatment plants do not appear to constitute a significant environmental hazard.

22) SULFATES

In U. S. waters that support good game fish, 5 percent of the waters contain less than 11 ppm of sulfates, 50 percent less than 32 ppm and 90 percent less than 90 ppm (Hart *et al.*, 1945). Experiments indicate that water containing less than 0.5 ppm of sulfate will not support growth of algae (Beauchamp, 1953). Sulfates are not felt to constitute an environmental hazard in the Merrimack River.

23) SULFIDES

Sulfides enter the water as constituents of many industrial wastes. The addition of soluble sulfides to water, results in a reaction with hydrogen ions to form HS^- or H_2S, the proportion of each depending upon the pH of the water. Sulfides derive their toxicity from undissociated H_2S, which at a pH of 5 or 6 accounts for about 99 percent of the sulfides present in water. In neutral waters the sulfides appear in about equal proportion of HS^- and H_2S, and at a pH of 9 most of the sulfides are in the form of HS^- (NAS, 1972). Because most

H_2S formation occurs at the mud-water interface, invertebrates, fish eggs and fry may be seriously affected by H_2S production. Tabulated data on the toxicity of hydrogen sulfide to various fish species in all stages of development revealed 96-hour LC_{50} values ranging from 0.0018 to 0.071 ppm and safe values ranging from 0.002 to 0.015 ppm (NAS, 1972). The data suggest that fish eggs are the least sensitive and fry the most sensitive to H_2S exposure.

Hydrogen sulfide is quite toxic to marine organisms, due in part to its fairly high solubility in water (437 g/100 ml at 0°C in pure water). Small amounts of hydrogen sulfide are fatal to sensitive species, such as trout, at concentrations of 0.05 ppm even in neutral and somewhat alkaline solutions (Doudoroff, 1957). Hydrogen sulfide in bottom sediments can affect benthic invertebrate populations (Thiede, *et al.*, 1969).

The EPA (1973) has set the maximum acceptable level of sulfides in natural waters as follows:

1) Freshwater (aquatic life)
   a. maximum total sulfides $<$ 0.002 ppm

2) Marine and Estuarine (aquatic life)
   a. 1/10 96-hour LC_{50} most sensitive/important species
   b. not to exceed 0.01 ppm

24) SUSPENDED AND SETTLEABLE SOLIDS

Suspended and settleable solids include such materials as sand, clay, finely divided organic material, bacteria and plankton. The principal sources which contribute these materials to the aquatic environment are agricultural runoff, construction activities, industrial operations, storm sewers, and municipal waste. The suspended and settleable solids and the sediments of a water body must be considered as interrelated, interacting parts. The significance of suspended particles in surface waters lies in their effects on light penetration, temperature, solubility products and aquatic life. These materials can be abrasive; blanket bottom deposits and fauna, either killing the organisms or rendering the habitat unsuitable; or serve as a transport medium for pesticides and other toxic material. The European Inland Fisheries Advisory Commission (1971, in EPA, 1973) states that concentrations of suspended solids of less than 25 ppm have no harmful effects on fisheries.

Natural waters with 25 to 80 ppm suspended solids should be capable of supporting good to moderate fisheries, while waters with suspended solids concentrations greater than 80 ppm are unlikely to support a good freshwater fishery.

The EPA (1973) states that the following is the maximum acceptable limit of dissolved solids in natural waters:

1) Freshwater (aquatic life)
   a. never to exceed 80 ppm

25) <u>TOTAL DISSOLVED SOLIDS AND HARDNESS</u>

Total dissolved solids is the general term describing the concentrations of dissolved materials in water. In natural surface waters, the total dissolved solids are primarily carbonates, sulfates, chlorides, phosphates, and nitrates. The quantity and quality of dissolved solids are major factors determining the diversity and abundance of aquatic communities. Hardness of surface waters is a component of total dissolved solids, chiefly being attributable to calcium and magnesium ions.

Total dissolved solids and hardness *per se* have no biological significance (EPA, 1973), but do serve as general indices of water type, buffering capacity and productivity.

26) <u>TURBIDITY</u>

Turbidity is largely determined by the same factors which influence suspended solids. Turbidity inhibits light penetrations, thus reducing the depth at which photosynthesis may occur. In addition, it may also interfere with vertical mixing and heat, and oxygen transfer. Finely divided suspended solids in excessive amounts may also import upon the fishery directly, inhibiting growth or egg and larvae development, interfering with natural movements, and reducing the fish's ability to capture food organisms (European Inland Fisheries Advisory Commission, 1971 in EPA, 1973).

The EPA (1973) states that added turbidity in natural waters should not alter the compensation point > 10 percent.

27) COLOR

True water color is the result of substances in solution after the suspended materials have been removed. Color may be derived from mineral or organic sources and is the product of natural as well as man induced processes. Its effect on the aquatic ecosystem is similar to that of turbidity.

The EPA (1973) states that changes in water color should not be of such magnitude so as to vary the compensation point > 10 percent.

28) pH

Extremes of pH can exert stress on or kill aquatic life. Even moderate changes from natural conditions are deleterious to some aquatic species. Fish food organisms appear to require a generally more narrow pH range than do fish. For example, *Daphnia magna* and *Gammarus* do not reproduce at pH levels below 6.0 (EPA, 1973). Alkaline conditions above pH 8.5 begin to decrease the fecundity of many fish species (EPA, 1973).

Very little is known about the direct effect of pH on marine organisms. However, it is known that even slight pH changes in the marine environment can be extremely significant, since even a slight change in pH indicates a drastic change in the buffering capacity of the seawater medium and the existence of potential or actual carbon dioxide imbalance.

The EPA (1973) specifies the following regarding acceptable pH levels in natural waters:

1) Freshwater (aquatic life) pH 6 - 9

2) Marine and Estuarine water (aquatic life) pH 6.5 - 8.5

29) TAINTING SUBSTANCES

Discharges from municipal wastewater treatment plants and a variety of industrial wastes and organic compounds, as well as certain organisms, can import objectional taste, odor or color to fish and other edible organisms. Such tainting can occur in waters with concentrations of the objectionable material lower than that recognized as harmful to aquatic life (see Tables 52 and 53).

Although many of these materials are present in secondarily treated wastewater, their exact concentration has not been prescribed for proposed secondary effluents entering the Merrimack River and its tributaries.

b) EVALUATIVE CRITERIA

1) RATIONALE

Abiotic changes in the environment induced by nature or man, initiate and influence biotic responses. An example of the interaction of abiotic and biotic components of the environment may be found when a combined domestic and industrial effluent containing a variety of materials which may act as nutrients, toxicants, oxygen demanding substances, or a combination of these is introduced into a water system. Should enough effluent enter the aquatic environment, noticeable changes in the biota will occur. For instance, the primary producers (phytoplankton, aquatic vascular plants) under given conditions can, with increased nutrients, change in species composition and grow to nuisance levels of abundance.

When a rapid growth of "bloom" condition develops, grazing organisms may not be numerous enough to keep the burgeoning load of plant material in check. This burden is then transferred to the decomposer chain. In the process of decomposition, oxygen levels are reduced, producing a stress on sensitive members of the aquatic community (such as game fish and their food organisms). Toxic materials also present in the effluent, acting alone or in concert with lowered dissolved oxygen, can act to kill, injure, or drive off organisms which are considered indicative of a healthy aquatic ecosystem.

Since abiotic factors differentially affect the various members of the biotic community (eliminate the sensitive forms and encourage the more tolerant ones), the community structure will be altered. The resulting community will generally support a smaller species diversity but a greater abundance of these forms remaining in the community. This type of a "degraded" community structure has been evident in biological surveys of the Merrimack River watershed. It is fortunate that

TABLE 52.
CONCENTRATIONS OF CHEMICAL COMPOUNDS IN WATER THAT CAN CAUSE TAINTING OF THE FLESH OF FISH AND OTHER AQUATIC ORGANISMS[1]

CHEMICAL	ESTIMATED THRESHOLD LEVEL IN WATER (concentration in ppm)
acetophenone	0.5
acrylonitrile	18
cresol	0.07
m-cresol	0.2
o-cresol	0.4
p-cresol	0.12
cresylic acid (meta para)	0.2
N-butylmercaptan	0.06
o-sec. butylphenol	0.3
p-tert. butylphenol	0.03
o-chlorophenol	0.0001 to 0.015
p-chlorophenol	0.01 to 0.05
2,3-dichlorophenol	0.084
2,4-dichlorophenol	0.001 to 0.014
2,5-dichlorophenol	0.023
2,6-dichlorophenol	0.035
2, methyl, 4-chlorophenol	0.075
2, methyl, 6-chlorophenol	0.003
o-phenylphenol	1
2,4,6-trichlorophenol	0.003 to 0.05
phenol	1 to 10
phenols in polluted river	0.02 to 0.15
diphenyl oxide	0.05
, -dichlorodiethyl ether	0.09 - 1.0
o-dichlorobenzene	0.25
ethylbenzene	0.25
ethanethiol	0.24
ethylacrylate	0.6
formaldehyde	95
kerosene	0.1
kerosene plus kaolin	1
isopropylbenzene	0.25
naphtha	0.1

Continued

TABLE 52. Continued

CHEMICAL	ESTIMATED THRESHOLD LEVEL IN WATER (concentrations in ppm)
naphthalene	1
naphthol	0.5
2-naphthol	0.3
dimethylamine	7
-methylstyrene	0.25
oil, emulsifiable	15
pyridine	5 to 28
pyrocatechol	0.8 to 5
pyragallol	20 to 30
quinoline	0.5 to 1
p-quinone	0.5
styrene	0.25
toluene	0.25
outboard motor fuel, as exhaust	2.6 gal/acre-foot
guaiacol	0.082

[1] EPA 1973

TABLE 53.
WASTEWATERS FOUND TO HAVE LOWERED THE PALATABILITY OF FISH FLESH[1]

SOURCE	CONCENTRATE IN WATER	SPECIES
Municipal Untreated Sewage (2 locations)	----	Channel Catfish *(Ictalurus punctatus)*
Municipal wastewater (4 locations)	----	Channel Catfish
Municipal wastewater (primary treatment)	11-13% by volume	Freshwater Fish
Municipal wastewater (secondary treatment)	20-26% by volume	Freshwater Fish

[1] modified from EPA (1973)

river systems are capable of "recovery", and that with proper wastewater management a reduction in potentially harmful abiotic inputs can result in the upgrading of present biological conditions to the point where a more healthy, diverse biotic community will prevail.

Since abiotic inputs either directly or indirectly affect all components of the biotic community, the evaluative approach taken will address itself to the question of the potential positive, negative, or neutral impacts of various wastewater management alternatives on the entire aquatic ecosystem.

2) APPROACH

The approach taken will be to divide the list of wastewater constituents into an "A" list (Table 54) (those present in the effluent water in environmentally damaging concentrations) and a "B" list (Table 55) (those present in the effluent with concentrations below known environmentally damaging levels or having neutral or poorly defined impacts). The "A" list will be used to generally address the local (areas near the proposed outfall) environmental impact of the unmixed effluent.

Using the approximate base line concentrations of the various parameters identified as present in the river system and known to be environmentally damaging ("A" list), the diluted levels of these parameters will be estimated for locations downstream from the outfall by using equation (2), page 272. From information developed by this procedure, the projected impact of the diluted constituent will be assessed both individually and collectively with other parameters of known environmental influence.

In analyzing the potential impact of both the undiluted and diluted components of effluents reaching the Merrimack watershed, reference will also be made to those contaminating components which at this writing do not appear at levels which are considered deleterious to the ecosystem (B), but which may interact, complement, or synergize with other components or those which may be biomagnified through chronic exposure. This evaluation process is illustrated schematically in Figure 26.

TABLE 54. "A" LIST FOR SECONDARY AND AWT EFFLUENT CONSTITUENTS OF EFFLUENT USUALLY PRESENT IN ENVIRONMENTALLY DAMAGING AMOUNTS

	SECONDARY	AWT
Nitrogen	X	X
Phosphorous	X	X
Ammonia	X	X
Chlorine[1]	X	X
Phenols	X	
Cadmium	X	
Chromium	X	
Copper	X	
Lead	X	
Mercury	X	
Manganese	X	
Nickel	X	
Zinc	X	

[1]Chlorine, while not listed in the effluent constituents, is of primary importance to the aquatic ecosystem.

TABLE 55. "B" LIST FOR SECONDARY AND AWT EFFLUENT

Cyanides
Polychlorinated Biphenyls
Phthalate Esters
Surfacants
Oils
Pesticides
Aluminum
Arsenic
Iron
Magnesium
Silver
Sodium
Boron
Chlorides
Sulfates
Sulfides
Suspended and Settleable Solids
Total Dissolved Solids
Hardness
Turbidity
Color
pH
Tainting Substances

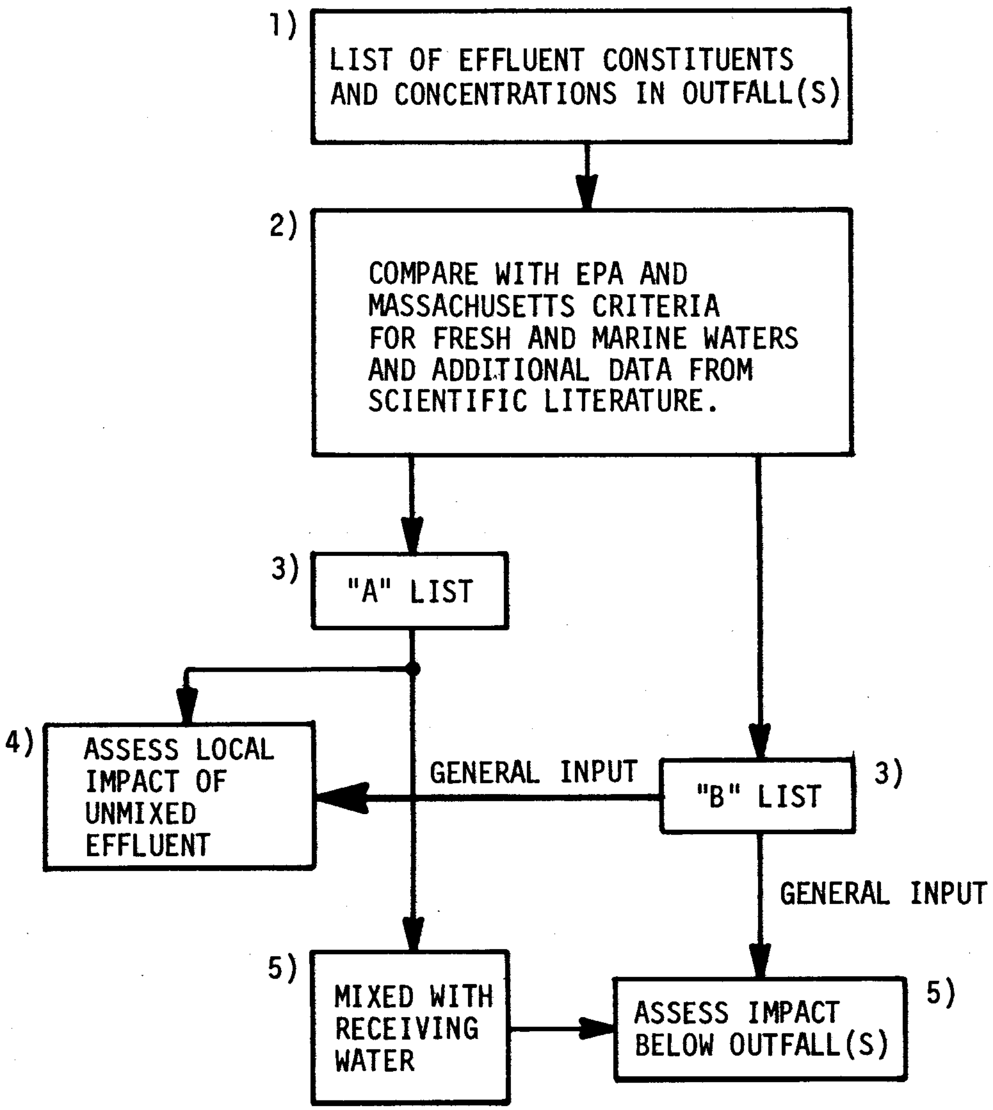


Figure 26. Schematic description of environmental impact evaluation for wastewater management alternatives.

B. TERRESTRIAL ECOSYSTEMS

1. Introduction

Application of wastewater effluent and sludge to land is undoubtedly an attractive alternative to the release of wastes directly into a waterway, because the impacts, whatever they may be, can be more effectively localized. Problems of drift or spread of waste constituents on land are not nearly of the same scale as in water. Terrestrial systems also have a greater inherent capacity to protect themselves against changes in abiotic variables; wastewater inputs large enough to disrupt the balance of an aquatic ecosystem would be absorbed by a terrestrial system with relatively less disturbance. Ideally, the terrestrial ecosystem should become an integral part of the waste treatment process, with autotrophic plants taking up essential nutrients, and decomposer organisms breaking down organic wastes.

It must be pointed out however that neither land disposal or any other treatment process is the universal solution to waste problems. Development of viable wastewater management programs must be based on regional and local site conditions and environmental factors. Without proper consideration of these factors, land disposal might temporarily protect water quality at the cost of permanent damage to the land. For example, terrestrial ecosystems are successful in removing the easily degraded organic compounds of domestic sewage. However, heavy metals, complex organics and inorganics, and toxic components of industrial or combined municipal wastes could initiate substantial long term problems.

One of the principal purposes of this study is to assess the environmental impacts of applying wastewaters and sludges to terrestrial ecosystems, as well as to determine the effectiveness of land systems in renovating wastewaters within the Massachusetts portion of the Merrimack River Watershed. To accomplish this objective, eighteen sites in the watershed and two sites on Cape Cod were selected for intensive study. These sites are intended to typify the botanical, zoological, hydrologic, physiographic, and edaphic conditions which prevail throughout the region.

2. Methods and Materials

On-site investigations at twenty designated sites (Figure 27), as well as a literature search, were undertaken to establish

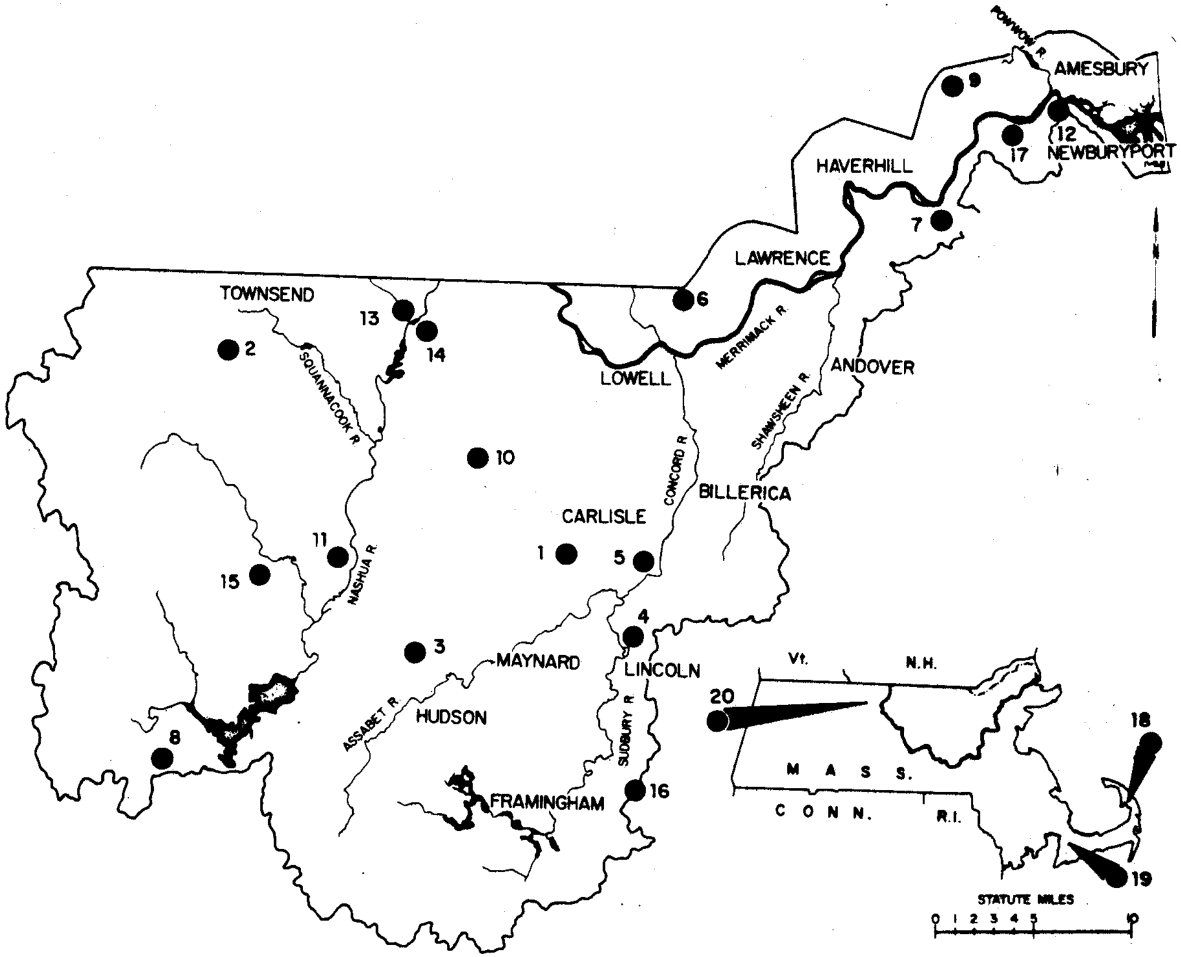


Figure 27. Location of twenty terrestrial sites in northeastern Massachusetts and Cape Cod, which were sampled during the Fall, 1973.

base line ecological conditions of terrestrial ecosystems throughout the Massachusetts portion of the Merrimack River watershed and on Cape Cod. From this research the following information has been compiled: 1) climatological conditions, 2) physiographic characteristics, 3) a description of the physical and chemical properties of the major soil series, 4) ground water quality, 5) species composition and relative abundance of principal plant, bird and mammal species, including a brief description of their habitat requirements, 6) a description of the major groups of soil organisms, and 7) estimates of annual productivity of the major soil series, with regard to grain and seed crops, forage, and forest production.

a) CLIMATOLOGICAL DATA

A description of the climatology of eastern Massachusetts was obtained from the U. S. Department of Commerce: National Oceanic and Atmospheric Administration, Environmental Data Service. Climatological data was compiled from four weather stations. Locations of these stations and the number of years of data evaluated are shown below:

Nantucket, Massachusetts:	1968-1969
Worcester, Massachusetts:	1968-1972
Milton, Massachusetts (Blue Hill Observatory):	1968-1972
Boston, Massachusetts:	1968-1972

b) PHYSIOGRAPHIC DATA

A discussion of the general physiographic conditions of northeastern Massachusetts and Cape Cod was prepared from a review of the literature. Descriptions of the physiography of the twenty sites were obtained from U. S. Geological survey topographic maps.

c) EDAPHIC DATA

Detailed descriptions of the major soil series on each site provided a basis for describing the general edaphic characteristics throughout eastern Massachusetts and Cape Cod. This information was provided by the U. S. Department of Agriculture, Soil Conservation Service via existing county soil surveys, and from interviews with scientists in county conservation offices. The major soil series encountered have been grouped on the basis of origin and development. For each series the following information was obtained: textural classes, depth to bedrock, infiltration and permeability rates, existence and depth of hardpan or impervious layers, stoniness, depth and duration of seasonally high water table, cation exchange capacity and percentage composition of organic carbon.

d) GROUNDWATER QUALITY

Descriptions of groundwater quality for eastern Massachusetts were obtained from the U. S. Geological Survey (1971) and the Massachusetts Department of Public Health (1971 & 1972). Groundwater data was obtained by testing the water quality of specific wells within various towns in the region. Groundwater quality is discussed by geo graphic location. Water quality characteristics for the Newburyport area were determined by analysis of data from 8 towns in Essex County; data for northcentral Massachusetts were derived from one town in Essex County, one town in Norfolk County, 16 towns in Middlesex County and ten towns in Worcester County. Data for Cape Cod were derived from wells in five towns in Barnstable County.

e) BOTANICAL DATA

Each site was surveyed to determine the relative size, distribution and species composition of the plant communities within its boundaries. Several transects were made through each site and the major species of plants in each community were recorded. Most species were identified in the field. However, unknown plants were collected, pressed, and identified in the Herbarium at the University of New Hampshire. Habitat requirements of the principal species of trees, shrubs and groundcover in forested ecosystems and grasses, woody and herbaceous vegetation of pastures, fields and orchards were obtained from a literature survey.

f) ZOOLOGICAL DATA

Data regarding the dominant species of mammals and birds of eastern Massachusetts and Cape Cod, including their habitat requirements, were obtained from the literature and interviews with personnel of the Massachusetts Division of Fisheries and Game as well as mammologists at Harvard University. Bird census data for eastern Massachusetts for years 1966-1972 were provided by the U. S. Bureau of Sport Fisheries and Wildlife.

A discussion of the major groups of soil organisms, in a typical soil profile including their relative abundance, importance and habitat requirements was obtained from the literature.

g) ANNUAL PRODUCTIVITY

The productivity of the major soil series in northeastern Massachusetts and Cape Cod has been determined on the basis of suitability for: 1) grain and seed crops; 2) grasses and legumes (forage and hay production); and 3) hardwood and coniferous forests. Data have been obtained on estimated yields of grains and seed crops and grasses and legumes as well as forestry site indexes for northern hardwoods upland oaks, white pine, and red pine. The forestry site index estimates the height of the dominant trees at the end of 50 years.

3. Climatology

Eastern Massachusetts has a humid climate with warm to hot summers and moderately long cold winters. The area is in a zone of prevailing west to east atmospheric flow. The variety and changeability of weather patterns results from the drift of north and southward movements of large air masses from tropical and polar regions. Systems of low air pressure frequently move into the area causing fluctuations from fair to cloudy or stormy conditions. The proximity of most of the region to the Atlantic Ocean moderates extremes of cold in winter and heat in summer. Summary of weather data for the weather stations in eastern Massachusetts is presented in Appendix B.

a) PRECIPITATION

Total precipitation (approximately 45 inches per year) is fairly evenly distributed throughout the year. March is normally the wettest month (approximately 4 1/2 inches) whereas July is normally the dryest (approximately 3 inches). Rarely is there a dry spell at any time of more than two weeks duration. On the other hand, extremely rainy periods are frequent. Occasionally up to six inches may fall in 24 hours. Eastern Massachusetts receives measurable precipitation on about 130 days out of the year (approximately 36%). Yearly rainfall during the past 42 years has ranged from a low of about 24 inches in 1965 to a high of about 65 inches in 1972.

b) HUMIDITY

Relative humidity is higher at night (approximately 75 percent at 0100 hours) than during the day (approximately 58 percent at 1300 hours). Values reach a nightly maximum (up to 87 percent) during August and September for the mainland areas. On Cape Cod maximum nightly humidity occurs during June. Values reach a minimum (as low as 47 percent for the mainland; and 65 percent for Cape Cod) during April and May. Yearly maximum averages range from 71-79 for the mainland and 85-86 for Cape Cod; minimum averages range from 56-59 for the mainland and 70-71 for the Cape.

c) SNOWFALL

The main snow season extends from late November to early April. Storms can occur at any time during this period, but heaviest storms are expected in February and March (up to 45 inches per month). Along the coast the winter "north-easters" usually produce mostly rain but, under the proper conditions, snowfalls of up to 2 feet in 24 hours can occur. This amount is much more likely to fall and persist as snow in the western (inland) sections. Annual snowfall averages about 30 inches on Cape Cod, 43 inches at Boston, about 60 inches in Essex and Middlesex County, and 79 inches in Worcester County. Snow cover is intermittent along the coast usually lasting only a few days at a time, except after unusually heavy storms or very cold weather. Away from the coast snow may be expected to cover the ground continuously for two or three months depending on exposure. On Cape Cod there is an average of 8 days with an inch or more of snowfall; for Boston the figure is 11 dyas; for the western sections it is 16 to 19 days. During the winter season, only one or two days are expected to produce more than 10 inches of snow. Measurable accumulations of snow (0.1 inch or more) have fallen at Blue Hill Observatory, (Milton, Massachusetts) on an average of 37 days of the year (approximately 10 percent) for the past 87 years.

d) TEMPERATURE

In the metropolitan Boston area, the mean annual temperature is 58.2°F (14.5°C). On Cape Cod it is about 50°F (10°C), and at Worcester, 47°F (8.4°C). Mean temperatures for the coldest month (January) are 31.4°F (-0.4°C) for the Cape Cod area, 28.4°F (-2.0°C) for the Boston area, and 24.0°F (-4.5°C) for the Worcester area. Mean temperatures for the warmest month (July) are 72.3°F (22.4°C) for Boston, 69.8°F (21°C) for Worcester, and 68.0°F (20°C) for Cape Cod. Mean daily maximum air temperatures for interior regions are 28°F in January and 81°F in July; minimums are 8°F and 57°F, respectively. For the seaboard the corresponding values are: maximum, January, 32°F, July 80°F; minimum, January 15°F, July, 59°F. The lowest recorded temperature is -24°F (-31°C) recorded on 16 February 1943 at Worcester, Massachusetts. A low of -21°C was recorded at Blue Hill, Milton, Massachusetts in February 1934. The highest temperature is 102°F (38.0°C) recorded at Worcester on 4 July 1911. Blue Hill records show a high of 101°C in August 1949. On the seacoast, the moderating influence of the ocean is evident, particularly with respect to low temperature extremes. In the past 72 years the lowest temperature recorded on Nantucket Island was -6°F, the highest, 95°F.

e) FROST

Freezing temperatures may occur anytime from the beginning of October to early May beginning in the more frostprone low lying inland valleys and finally reaching the shore areas of Cape Cod. The average earliest freezing date at Winter Hill, Worcester, Massachusetts is 3 October, the latest, 7 May. At Blue Hill, Milton, Massachusetts values are 21 October for the average earliest date and 26 April for the latest. At Logan International Airport in Boston, the values are: earliest, 7 November; latest, 8 April.

The average length of the frost free period is about 210 days along the coast, about 180 days in Essex County, and varies from 150 to 170 further inland depending on exposure. Along the coast an average of 20 days per year have temperatures which do not rise above freezing sometime in 24 hours. The average number of subfreezing days rises considerably as one travels inland (44 at Milton, 56 at Worcester). Minimum temperatures drop to or below the freezing point on an average of 105 days along the coast, 132 days at Milton, and 148 days at Worcester.

f) SOLAR RADIATION

The mean annual value of solar radiation for eastern Massachusetts is approximately 320 langleys.* Due to cloudiness, December is the dullest month, receiving only about 46 percent of possible sunshine (127 langleys). June is the brightest month receiving about 62 percent of possible sunshine (510 langleys).

g) WIND

The prevailing wind direction is from the southwest particularly in the warmer months (May through November). In winter and early spring the prevailing direction is generally from the northwest. Wind speeds average about 13 m.p.h. (21 kilometers per hour). Like prevailing direction, wind speed shows a strong seasonality (Figure 28). The slowest winds occur in August (average speed: 11.3 m.p.h., 18.2 km/hour), while the fastest occur during the winter months, January through March (average 15 m.p.h., 24.1 km/hour). The highest wind speed expected during winter storms is 76 m.p.h. (122 km/hour). Hurricanes are a source of much higher winds (August, 1938, 121 m.p.h., gusts to 186 m.p.h.).

h) EVAPOTRANSPIRATION

The amount of water returning to the atmosphere from the

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* A langley equals the energy falling on a surface 1 cm^2, which would raise the temperature of 1 gram of water 1°C.

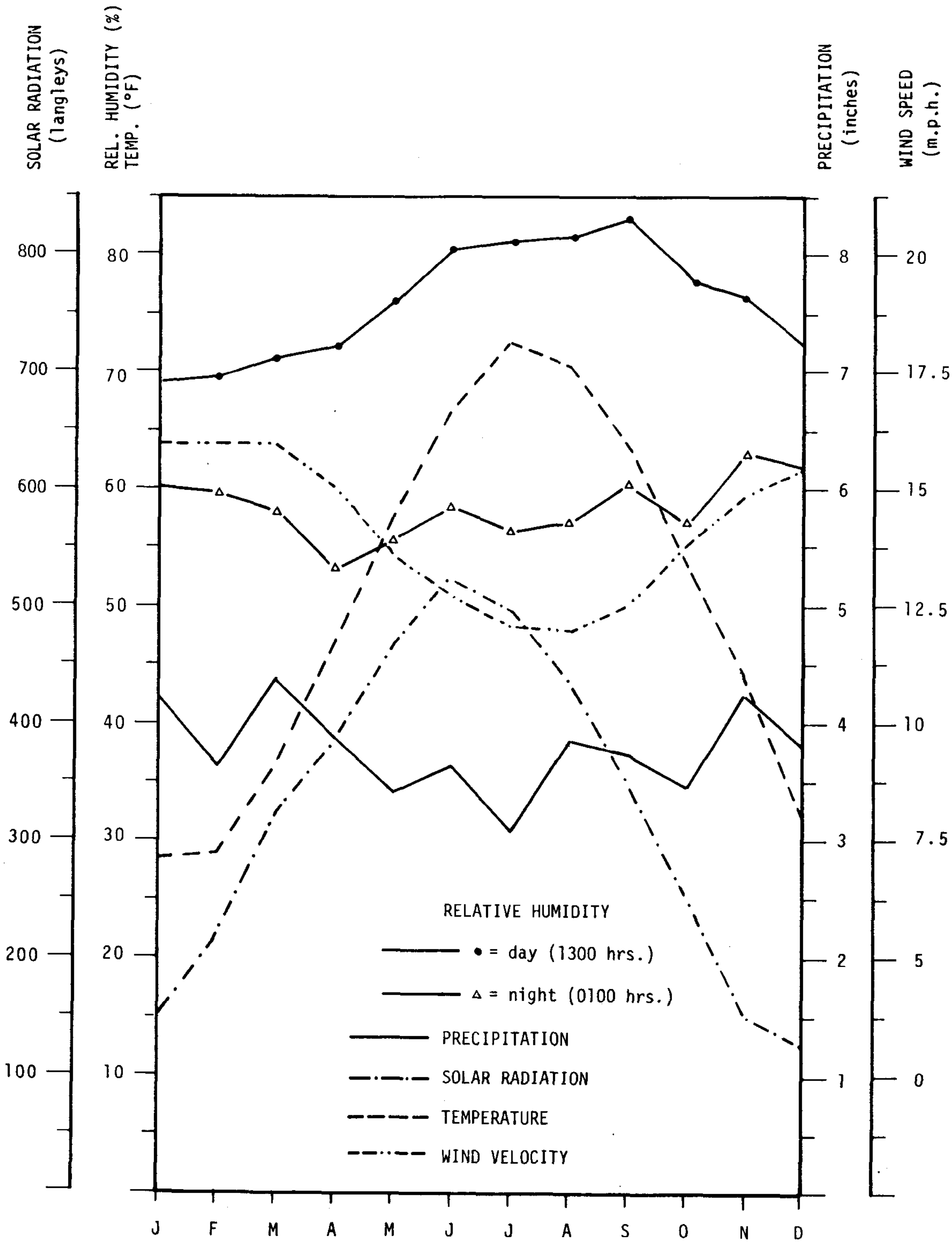

Figure 28. Summary of Monthly Climatological Data for Eastern Massachusetts.

ground and vegetation depends on a number of the climatological factors described above, namely temperature, solar radiation, relative humidity and wind speed. Temperature is the most important factor. In eastern Massachusetts an average of about three quarters of the total yearly evaporation occurs during the warmest months, from May to October. Mean annual potential evapotranspiration for the region is about 24 inches per year.

i) RUNOFF

The mean annual surplus of water available for resupply of ground and surface waters is about 20 inches. Most of the surplus water, stored during the colder months as snow and ice becomes available during "spring runoff". March is normally the month of greatest precipitation. The combination of thawing temperatures and excess precipitation makes early spring the time of maximum surplus water runoff.

General climatological conditions throughout the study area are illustrated in Figure 28, which is based on compilations of many years of data from two eastern Massachusetts weather stations. Mean monthly variations of relative humidity, precipitation, solar radiation, temperature and wind velocity are depicted during a typical year. Seasonal cycles of solar radiation, wind speed, daytime humidity and temperature are clearly evident. Precipitation and nighttime humidity do not exhibit patterns of seasonal fluctuation.

4. Physiography

Eastern Massachusetts can be divided into three physiographic regions: the New England Upland region, the New England Seaboard region and the Coastal Plain region.

The New England Upland region, which encompasses most of western Massachusetts including the major portion of Worcester County, consists of an upraised plain that is underlain by granite, gneiss, schist, slate and shale. Many lakes, drumlins, and a few isolated hills (monadnocks), relics of glacial activity, are scattered throughout the region. Elevations range from 500 to 1,500 feet.

The New England Seaboard region, which includes portions of eastern Worcester county as well as Middlesex and Essex counties, is a narrow strip of coast bounded on the west by 400 to 500 foot elevations above sea level. This area ranges in width from about 30-50 miles and is underlain by sandstone, shale, slate and granite.

The Coastal Plain area includes Cape Cod which extends about 25 miles eastward from the mainland and then about 30 miles north and northwest. Maximum elevations on the Cape are less than 300 feet above mean sea level. Cape Cod consists almost entirely of material deposited by glaciers and subsequently reworked into its present configuration by winds, waves, and ocean currents. In marked contrast with the rest of New England, the bedrock on Cape Cod lies several hundred feet below the land surface.

Physiographic descriptions of the twenty terrestrial sites is presented in Appendix C.

5. Soils

Soils of northeastern Massachusetts are predominantly stony to very stony sandy loams or loans, low in silt and clay, strongly acidic, mostly well to moderately well drained, deep to moderately deep with some areas of bedrock outcroppings. Soils on Cape Cod are primarily sandy loams, very deep, strongly acidic, and well drained.

Soils in the region, however, are quite variable and differ according to the nature of their parent material. In the glaciated regions, (such as New England), parent materials are: glacial till; water-sorted sand and gravels on terrances and deltas; and clay, silt and fine sand lake sediments, derived from many kinds of bed-rock, principally granite, gneiss, schist, sandstone, shale, slate, phyllite and limestone. Certain soils are derived from organic material which has undergone various stages of decomposition. In the following discussion, the principal soil series encountered on the twenty terrestrial sites have been grouped into five categories based on parent material associations.

The principal soil series derived from glacial till are Acton, Charlton, Essex, Hollis, Paxton, Ridgebury, Scituate, Sutton, Whitman, and Woodbridge. These soils were generally developed from compacted or firm glacial till material, except for the Acton series, which were developed from loose till, and Hollis, Sutton and Whitman which may be derived from either loose or firm material. Hollis soils are usually very shallow (two feet or less in depth) whereas the other glacial till soils range in depth from 3-30 feet. Acton, Charlton, Essex and Paxton are well drained; Scituate, Sutton and Woodbridge are moderately well drained. Ridgebury and Whitman soils are poorly drained. Most soils in this group have a hardpan or impervious layer at depths ranging from 1.0 to 2.5 feet with the exception of Sutton soils which have a hardpan at a depth of 3.0 to 5.5 feet. Hollis soils do not have an impervious layer. Surface horizons in glacial till soils are usually of a fine sandy loam texture, except for Scituate which has a sandy loam and Whitman which has black loam topsoil. Subsoils are textured identically to the surface layers within this group, except for Acton, Essex, and Scituate, which have a loamy sand texture. Ridgebury and Whitman soils are saturated with water during 4-5 months each year, primarily during late fall, winter and early spring. The remaining series are saturated with water for very short periods of time.

Canton and Narragansett soils have developed in a mantle of fine sandy loams, fine sand and silts which are underlain by glacial till. They are well drained soils. These soils do not have an impervious layer but are underlain by compacted glacial till which is moderate to slowly permeable. They have a fine sandy loam surface and subsoil. Neither series is subject to prolonged periods of water saturation.

The principal soil series derived from deep deposits of sand and gravel include: Agawam, Au Gres, Carver, Deerfield, Elmwood, Hinckley, Merrimac, Ninigret, Scarboro, Sudbury, Swanton, and Walpole. Agawam, Carver, Deerfield, Elmwood, Ninigret, Swanton and Windsor are derived from sand deposits and the remaining series from sand or sand and gravel. Agawam, Deerfield and Elmwood are well drained whereas Ninigret and Sudbury are moderately well drained. Au Gres, Scarboro, Swanton and Walpole are poorly drained. Only two series in this group, Elmwood and Swanton, have hardpans which occur at depths of 1.5-3.0 feet. The surface textural character of most soils in this group is fine sandy loam. However, Deerfield, Hinckley and Windsor have a loamy sand texture; Carver has a loamy coarse sand texture; Au Gres has a sand texture and Scarboro has a surface texture of black sand and muck. Subsoil characteristics are identical to that of the surface soil for most of the series. Merrimack, Sudbury and Walpole have a sandy loam substrate and Hinckley and Scarboro have sand or sand and gravel subsoils. A variant of the Ninigret series has a silty subsoil. Au Gres, Scarboro, Swanton and Walpole are saturated with water during most of the year; Deerfield, Elmwood, Ninigret and Sudbury soils are saturated for 4-5 months each year during winter, early spring or periods of heavy rainfall. The remaining series do not have lengthy periods of water saturation.

The following soils have developed in deep fine sand, silt and clay deposits: Buxton, Engield, Hadley, Limerick, Saco and Winooski. Hadley, Limerick, Saco and Winooski soils have formed in recent floodwater deposits by streams and rivers. Enfield soils have formed in fine sand deposited by wind. Buxton soils have developed on marine and glaciolacustrine deposits. Enfield, Hadley and Winooski are well drained; Buxton is moderately well drained and Limerick and Saco soils are poorly drained. The soils in this group do not have impervious layers; however, the Buxton series have a substratum that is slowly permeable. The surface texture of this group is equally divided between silt loams (Buxton, Limerick, Saco) and very fine sandy loams (Enfield, Hadley, Winooski). The subsoils are identical with the surface layers for all soils in this group. However, Limerick and Saco soils may have a very fine sandy loam subsoil. Alluvial deposit soils are subject to periodic flooding. Buxton and Winooski soils are saturated with water during 4-5 months each year especially in late fall and spring. Limerick soils are saturated for 7 months or more each year. Enfield is the only series in this group not subject to extensive periods of high water levels.

Muck soils have developed in deep or shallow accumulations of organic deposits. The upper portions have undergone considerable decomposition whereas the lower portions are relatively undecomposed. Muck soils are poorly drained and are subject to water saturation during most of the year.

Physical and chemical characteristics of the principal soil series are presented in Table 56. Descriptions of the existing edaphic conditions on twenty terrestrial sites are presented in Appendix C.

6) Ground Water Quality

Data obtained from chemical analysis of well water in Massachusetts are presented in Table 57. The data, originally reported as yearly average values of tests for each well, have been condensed to represent three regions within the study area. A listing of the well water quality on a town by town basis, for 41 towns in eastern Massachusetts is given in Appendix D.

Mean values for groundwater pH are fairly homogeneous throughout the study areas; the values are 6.6-6.7 for the Middlesex-Worcester County region and Northern Essex County, and 6.2-6.3 on the Cape. Values for pH (for all sites considered) ranged from 5.7 to 8.8, which are within the recommended range specified by the EPA for public water supplies (ph 5-9). Mean values of alkalinity are comparable between the mainland and the Cape (means range from 11-28 ppm) whereas values for the Newburyport area are slightly higher (39-54 ppm). Mean hardness ranges from lowest values (19-21 ppm) on Cape Cod to median values (51 ppm) on the mainland and highest

TABLE 56. PHYSICAL AND CHEMICAL CHARACTERISTICS OF MAJOR SOIL SERIES ENCOUNTERED ON 20 SITES IN EASTERN MASSACHUSETTS AND CAPE COD

Series	Texture Class Surface soil Subsoil	Stoniness (1)	Depth	Length of time saturated with water (months) (2)	Cation Exchange Capacity (3)	Permeability	Infiltration	Depth to Seasonal Water Table	Reaction (pH)	% Organic Carbon	Depth to slowly permeable or impervious layer (feet)
Acton	fine sandy loam loamy sand	VS MS	>3	a	≈27.6	mod.	mod.	1.5	4.5 - 6.0	≈2.99	>2.5
Agawam	fine sandy loam fine sandy loam	NS	>10	0	14.8	mod. rapid	mod.	3-5+	4.5 - 6.5	1.09	none
Au Gres	loamy sand loamy sand	NS	>10	7-9	29	mod. rapid	low	0-1	4.0 - 5.0	3.20	none
Buxton	silt loam silt loam	NS	>10	a	66.9	mod. slow	low	1.5	5.5 - 6.5	4.66	subsoil layers
Canton	fine sandy loam fine sandy loam	VS MS		0	≈33	mod. rapid	mod.			≈5.85	>3.5 permeability mod. - slow
Carver	loamy course sand loamy course sand	NS	>20	0	25.5	rapid	high	>5	4.5 - 6.0	3.27	none
Charlton	fine sandy loam fine sandy loam	MS	3-30+	0	33	mod. rapid	mod.	3-5+	4.5 - 6.0	5.85	>2.5
Deerfield	loamy sand loamy sand	NS	>10	b	26.8	rapid	mod.	1.5	4.5 - 6.5	2.10	none
Dukes	coarse sand coarse sand	NS	>10	0	12.2	rapid	high	3-10+		0.74	none
Elmwood	fine sandy loam fine sandy loam	NS	variable	c	≈23.9	mod. rapid	low	1-2	5.0 - 6.0	≈2.33	2.0 - 3.0
Enfield	very fine sandy loam very fine sandy loam	NS	>30	0	≥27.3	mod.	mod.	3-5+	4.5 - 5.5	≈1.15	none

Continued

TABLE 56. (Continued)

Series	Texture Class Surface soil / Subsoil	Stoniness (1)	Depth	Length of time saturated with water (months) (2)	Cation Exchange Capacity (3)	Permeability	Infiltration	Depth to Seasonal Water Table	Reaction (pH)	% Organic Carbon	Depth to slowly permeable or impervious layer (feet)
Essex	fine sandy loam	VS	3-20	0	26.2	mod. rapid	low	3-5+	4.5 - 6.5	2.50	≈2.0
Hadley	very fine sandy loam very fine sandy loam	NS	>10	d	39.6	mod. rapid	mod.	3-5+	4.5 - 6.0	3.14	none
Hinckley	loamy sand sandy-gravel	OS	>10	0	10.5	rapid	high	3-5+	4.5 - 6.5	1.12	none
Hollis	fine sandy loam fine sandy loam	VS	generally >2	0	≈33	mod. rapid	low very low	-	4.5 - 6.0	≈5.85	none
Limerick	silt loam silt loam	NS	>10	7+	≈39.6	slow	low	0-1	5.0 - 6.0	≈3.14	none
Merrimac	fine sandy loam sandy loam	OS NS	>10	0	27.3	mod. rapid	mod.	3-5+	4.5 - 6.5	1.15	none
Muck	decomposed organic matter non decomposed organic matter	NS	3-20+	e	high	low	very low	0		high	none
Narragansett	very fine sandy loam very fine sandy loam	MS		0	≥33	mod. rapid	mod.			≥5.85	1.5 - 2.5

Continued

TABLE 56. (Continued)

Series	Texture Class Surface soil Subsoil	Stoniness (1)	Depth	Length of time saturated with water (months) (2)	Cation Exchange Capacity (3)	Permeability	Infiltration	Depth to Seasonal Water Table	Reaction (pH)	% Organic Carbon	Depth to slowly permeable or impervious layer (feet)
Ninigret (silty subsoil variant)	fine sandy loam fine sandy loam (silty material)	NS	>10	b	32.2	mod. rapid	mod. low	1.5	4.5 - 6.5	2.75	none silty subsoil variant has slowly permeable subsoil
Paxton	fine sandy loam fine sandy loam	VS MS	>3	0	41.7	mod	low	>2	5.0 - 5.5	2.81	≈2.0
Ridgebury	fine sandy loam fine sandy loam	VS MS	3-20+	7-9	27.6	mod. slow	low	0-1	4.5 - 6.5	2.99	1.0 - 1.5
Saco	silt loam silt loam	NS	>10	e	≤39.6	mod.	very low	0	4.5 - 6.5	≤3.14	none
Saugatuck	sand sand	NS	>10		22.2	high	high	0-1		2.74	1.0 - 2.0
Scarboro	sand/muck	OS	>10	e	≤23.9	mod. rapid	very low	0	4.5 - 6.0	≤2.33	none
Scituate	sandy loam loamy sand	VS	3-20+	b	33.6	mod. rapid	low	1.5	4.0 - 6.0	4.17	1.5 - 2.5
Sudbury	fine sandy loam sandy loam	OS NS	>10	b	23.9	mod. rapid	mod.	1.5	4.5 - 6.5	2.33	none

Continued

TABLE 56. (Continued)

Series	Texture Class Surface soil Subsoil	Stoniness (1)	Depth	Length of time saturated with water (months) (2)	Cation Exchange Capacity (3)	Permeability	Infiltration	Depth to Seasonal Water Table	Reaction (pH)	% Organic Carbon	Depth to slowly permeable or impervious layer (feet)
Sutton	**fine sandy loam** **find sandy loam**	VS MS	3-30+	b	≈43.8	mod. rapid	mod.	1.5	4.5 - 6.5	≈3.33	3.0 - 5.5
Swanton	fine sandy loam fine sandy loam	OS	>10	7-9	≈23.9	rapid	low	0-1	4.5 - 6.5	≈2.33	1.5 - 2.5
Walpole	fine sandy loam sandy loam	NS	>10	7-9	≈23.9	mod. rapid	low	0-1	4.5 - 6.0	≈2.33	none
Whitman	loam with high organic matter fine loam	MS	3-10+	e	≈27.6	mod. rapid	very low	0	4.5 - 6.0	≈2.99	1.0 - 2.0
Windsor	loamy sand loamy sand	OS NS	>10	0	12.9	rapid	high	3-5+	4.5 - 6.0	1.06	none
Winooski	very fine sandy loam very fine sandy loam	NS	>10	a,d	44.8	mod. slow	mod	1.5	5.0 - 6.5	2.46	none
Woodbridge	fine sandy loam fine sandy loam	VS MS	>3	b	43.8	mod.	low	1.5	5.0 - 6.0	3.33	1.5

[1] Stoniness
VS = Very stony
MS = Moderately stony
OS = Occasionally stony
NS = Not stony

[2] a = late fall to early spring
b = winter, early spring or during prolonged periods of rainfall
c = spring and sometimes in the fall
d = subject to flooding
e = most of year

[3] Average Cation Exchange (CEC) of surface layers (meq./100gm).

TABLE 57. GROUNDWATER QUALITY IN TWO REGIONS OF THE MASSACHUSETTS PORTION OF THE MERRIMACK RIVER WATERSHED AND CAPE COD

(Data averaged from well water analysed by the Massachusetts Dept. of Public Health 1971 and 1972)

PARAMETER	NORTHERN ESSEX COUNTY 1971	NORTHERN ESSEX COUNTY 1972	MIDDLESEX-WORCESTER COUNTY REGION 1971	MIDDLESEX-WORCESTER COUNTY REGION 1972	CAPE COD 1971	CAPE COD 1972	E.P.A. DRINKING WATER STANDARDS
pH	6.7	6.7	6.6	6.6	6.3	6.2	5-9
Alkalinity (ppm)	39	54	24	28	11	26	no limit
Hardness (ppm)	69	74	51	51	21	19	no limit
Iron (ppm)	0.75	0.99	0.12	0.15	0.12	0.09	0.3 mg/l
Manganese (ppm)	0.12	0.16	0.12	0.17	0.09	0.05	0.05 mg/l
Ammonia N (ppm)	0.04	0.02	0.02	0.02	<0.01	<0.01	0.05 mg/l
Nitrate N (ppm)	0.4	0.6	1.0	0.8	1.6	1.0	10 mg/l
Chlorides (ppm)	31	29	30	33	34	39	250 mg/l
Sodium (ppm)	13	14	14	18	18	36	no limit
Potassium (ppm)	--	2.0	1.4	1.8	--	1.1	----
Silica (ppm)	--	17	9	13	--	12	----
Sulfate (ppm)	--	23	18	15	--	8	250 mg/l
Cond. $\frac{\text{micromhos}}{\text{cm}}$	--	227	200	185	--	190	----

values in the Newburyport area (69-74 ppm). Limits for alkalinity and hardness in public water supplies have not been proposed by the EPA.

Mean concentrations of metals vary slightly among the areas. Concentrations of iron are comparable between the mainland and the Cape with values ranging from 0.09 to 0.15 ppm. Levels of iron are higher in Northern Essex County ranging from 0.75-0.99 ppm. Concentrations of manganese and potassium are similar among the areas. Manganese ranges from a low of 0.05 ppm to a high of 0.17 ppm. Levels of potassium fluctuate between 1.1 and 2.0 ppm. Sodium levels are also comparable between each location ranging from 13 to 36 ppm. There are no EPA restrictions for sodium and potassium concentrations in public water supplies. Concentrations of manganese and iron exceed EPA maximum acceptable levels in many instances. High levels of iron and manganese can impart an undesirable taste to drinking water and stain clothes during laundering. High concentrations of manganese may possibly cause harmful physiological effects.

Concentrations of various non-metals such as chlorides and sulfates differ only slightly between each area. Chlorides range from 29-39 ppm, while sulfates vary from a low of 8 ppm to a high of 23 ppm. The maximum recommended concentration for public water supplies is 250 mg/l; thus levels in the groundwaters in the study areas show no cause for alarm.

Nutrients such as ammonia and nitrates are comparable between areas. Mean concentrations of ammonia range from 0.01-0.04 ppm. Values from individual wells range from a low of 0.00 ppm to a high of 0.27 ppm. Mean nitrate concentrations vary from 0.8 to 1.6 ppm in the Middlesex-Worcester County region and Cape Cod, and 0.4 to 0.6 in Northern Essex County. While nitrate values from individual wells are quite variable, all are well within the EPA recommendations (10 mg/l).

7. Biology

a) PLANTS

Two major forest regions are found in eastern Massachusetts. The white pine-hemlock hardwood forest association encompasses most of the state including the entire Merrimack River Watershed. Southeastern Massachusetts and Cape Cod are included in the yellow pine-hardwood forest region.

Species composition of the white pine-hemlock-northern hardwood forest varies greatly depending on site characteristics (primarily soil conditions). Most of the lands in the study area had been cleared for farming prior to the Civil War. Since then slow abandonment has taken place and now most of the region is forested. White pine stands were the first important forests to occupy these abandoned farmlands; since then most of these stands have been logged several times. Existing species composition is primarily dependent on the texture of the soils occupying the sites. On sandy soils, stands are still predominately white pine because of minimal competition from hardwood species. On loams or fine sandy loams, vigorous growth of shade tolerant hardwoods and hemlock have tended to exclude nearly pure stands of pine.

Logging practices have also influenced the composition of existing forest stands. In many areas there is a high percentage of hardwoods because sources of seed for softwoods have been removed by selective cutting of pine and hemlock. In addition, many stands are dominated with inferior trees as a result of high grading, i.e., removing the good quality trees and leaving poorer individuals. These stands cannot be economically managed until they are restocked with desirable trees. In many areas, hardwood stands have been clearcut for cordwood or charcoal; this heavy cutting favored the growth of even-aged stands of less shade tolerant hardwoods.

The most important softwood species in this region are white pine and hemlock. Dominant hardwood species include: red and sugar maple; red, white, black and scarlet oak; white, black and gray birch; white ash; beech; bitternut; sweet pignut and shagbark hickory; and American elm. Dominant species of upland sites with rich, moist soils include white pine, maple, oak, hickory, birch, beech, and ash. On dry, sandy, well drained soils pitch pine, white pine, gray birch, white and scrub oak are the primary species. In ravines nearly pure stands of hemlock are common. On old fields or pastures stands of white pine may be found, sometimes developing beneath such earlier invaders as gray birch, quaking and bigtooth aspen.

Primary understory vegetation of mature upland forests include tree saplings and various shrubs such as chestnut, highbush and lowbush blueberry, mountain and sheep laurel, mapleleaf viburnum, and smooth arrowwood. Principal groundcover species include: tree seedlings, hayscented and brachen ferns, club moss, trailing evergreen, ground pine, hairycap moss, partridge berry, teaberry, lady slipper, wild sarsaparilla, ground juniper and trailing rubus.

Interspersed throughout this forest region are field, pasture, orchard and other agricultural areas. Apple is the most important cultivated orchard tree throughout the state. Species found in open areas include various grasses (foxtail, broom bear, poverty, Rhode Island bent, redtop, fescue, tumble, orchard, Kentucky blue and timothy) and woody and herbaceous species such as: red field clover, wild carrot, meadow sweet, yarrow, goldenrods, hairy vetch, lady's sorrel, asters, cinquefoil, sweetfern, pigweed, dandelion and ragweed.

The yellowpine-hardwood forest association has the sharpest boundaries of any forest region because of its close association with coastal plain sands. The principal tree species on the impoverished soils of this area are drought resistant oaks and pines. Shrub thickets, mats of prostrate vines and openings in the canopy are typical of this forest. Extensive areas have been burned by wildfires. On some sites, repeated fires have stunted oak growth and killed off the pine, producing dense impenetrable thickets of waist- or head-high scrub oak.

The principal overstory species of this forest association are pitch pine, white and scrub oak. Associated species include black and scarlet oak, black locust, gray birch, bigtooth and quaking aspen. Frequent understory vegetation consists of tree saplings, various shrubs such as scrub oak, lowbush blueberry, bayberry and sheep laurel, and vines such as greenbriar. Ground cover is composed of tree seedlings, brachen fern, trailing rubus, fescue grass, teaberry and club moss.

Marshes are commonly encountered throughout Massachusetts. They are characterized by the absence of trees and shrubs with vegetation being composed of coarse grasses and sedges. In shallow water areas, emergents such as cattail and pickerel weed are common. In deeper water areas, water-lilies and duckweed are found on the surface while still other species are completely submerged.

Common plants of marshes include:

bur-reed	bulrush	tussock sedge
arrowhead	greatbulrush	three-way sedge
arrow-arum	three-square bulrush	spike rush
wool grass	umbrella sedge	purple loosestrife

yellow loosestrife
soft rush
rush
spatter dock
reed
wild rice
marsh fern
royal fern
sensitive fern
water plantain
blue-joint grass
fowl-meadow grass
reed-canary grass
rice cut-grass
beak rush
sweet flag
smartweeds
meadow rice
swamp St. John's wort
meadow beauty
swamp milkweed
forget-me-not
water horehound
turtle
Joe-pye weed
boneset
ironweed
bur marigold

Swamps occur commonly in the area and are dominated by wetland trees and shrubs. Red maple is the most characteristic tree but black gum, black willow and black oak are frequent associates. Principal shrubs are:

speckled alder
smooth alder
pussy willow
silky willow
highbush blueberry
maleberry
leatherleaf
sweet pepperbush
clammy azalea
winterberry
spicebush
buttonbush
chokeberry
marsh marigold
skunk-cabbage
cinnamon fern
interrupted fern
wood reedgrass
indian poke
goldthread
bitter cress
water carpet
steeple bush
meadow sweet
swamp rose
trailing swamp blackberry
jewelweed
violets
golden Alexanders
waterhemlock
water parsnip
water pennywort
silky dogwood
red-osier dogwood
rhodora
skullcap
arrowwood
witherod
elderberry
cardinal flower

Floodplains fringing watercourses are adapted to handle large volumes of water in times of flooding. Flood plains usually support a mosaic of vegetation types such as marshes, swamps or forests. Floodplain forests are dominated by black-willow, cottonwood and silver maple. These species are especially adapted to withstand flooding. Frequently there are three vegetative zones: willow along the unstable and eroding edges of the riverbank, cottonwood in an intermediate zone, and silver maple on older more stable deposits further from the riverbank. Alder are frequently found along streams, and buttonbush on floodplains which are deeply innundated every spring. Other plants of marshes and swamps are often present on the floodplain.

Detailed descpritions of the botanical characteristics of each site are presented in Appendix E. A checklist of the plant species encountered on the twenty terrestrial sites is included in Appendix F. Habitat characteristics of the principal overstory, understory and groundcover species of the white pine-hemlock-northern hardwood and yellow pine-hardwood forest regions and the principal woody, herbaceous, and grass species encountered in fields, pastures and orchards throughout the study area are presented in Appendix G.

c) BIRDS

Table 58 presents a list of bird species which occur in four plant communities found throughout eastern Massachusetts In reviewing this species list the following points must be kept in perspective: 1) the list is not meant to be exhaustive; 2) designated species may be common, uncommon or rare in abundance; 3) individual species within a particular habitat may be cosmopolitan or localized in distribution; and 4) particular species may be either permanent residents, residents during the breeding season, residents during the non-breeding season, spring migrants or fall migrants.

The greatest species diversity is encountered in agricultural habitats with a total of 60 species listed. Introduced plants comprise most of the orchard-field-cultivated areas and the general appearance of these areas is similar in both forested regions. The number of birds in these developed areas is greater now than when Europeans first began settling New England.

The white pine-hemlock-northern hardwood forest is ranked second in regard to species diversity with a total of 43 species of birds. This forest is mostly cut-over and is populated with sprout hardwoods or second growth and many understory and groundcover flora. Such stands are very productive of bird (and animal) life, more so than undisturbed mature forests which originally occupied the region.

The yellow pine-hardwood forest region is lower in species diversity with only 33 bird species. These forests do not have the diversity of plant species as the preceeding forest association. They are characterized by small trees, shrub thickets and more open areas. The floor is often nearly bare or matted with pine needles.

Freshwater marshes, with only 35 bird species, are very

TABLE 58. SPECIES OF BIRDS ASSOCIATED WITH FOUR PLANT COMMUNITIES OF EASTERN MASSACHUSETTS

(adapted from Bailey, 1955)

SPECIES	White Pine-Hemlock-Northern Hardwood region	Yellow Pine-Hardwood Region	Orchards, fields pasture and Cultivated land	Freshwater marshes
Alder Flycatcher				x
American Bittern				x
Baltimore Oriole			x	
Bank Swallow				x
Barn Owl			x	
Barn Swallow			x	x
Barred Owl	x	x		
Black-Billed Cuckoo			x	
Black-Capped Chickadee	x	x	x	
Bluebird			x	
Black Crowned Heron				x
Blue Jay	x	x		
Black Duck			x	x
Blue-Winged Teal				x
Bobolink			x	
Broad-Winged hawk	x			
Bronzed Grackle	x		x	
Brown Thrasher		x	x	
Catbird		x	x	
Chestnut-sided Warbler	x		x	
Chipping Sparrow		x	x	
Bobwhite			x	
Chimney Swift	x		x	
Cliff Swallow			x	x
Cowbird	x		x	
Crested Flycatcher		x	x	
Crow	x	x	x	
Downy Woodpecker	x	x	x	
Flicker	x	x	x	
Goldfinch	x	x	x	
Great Horned Owl	x	x		
Great Blue Heron				x
Green Heron			x	x
House Sparrow			x	
Black and White Warbler	x			
Blackburnian Warbler	x			

Continued

TABLE 58. Continued

SPECIES	White Pine-Hemlock-Northern Hardwood region	Yellow Pine-Hardwood Region	Orchards, fields pasture and cultivated land	Freshwater marshes
Black-throated Blue Warbler	x			
Black-throated Green Warbler	x	x		
Blue Headed Vireo	x			
Brown Creeper	x			
Blue-winged Warbler			x	
Cooper's Hawk	x			
Golden winged Warbler	x			
Grasshopper Sparrow			x	
Hairy woodpecker	x	x	x	
Florida Gallinule				x
Coot				x
Hermit Thrush	x			
Henslow's Sparrow			x	
House Wren			x	
Hummingbird			x	
Indigo Bunting			x	
Killdeer			x	x
Kingbird			x	
Kingfisher				x
Least Bittern				x
Least Flycatcher			x	
Long-eared Owl	x	x	x	
Long-billed Marsh Wren				x
Meadowlark			x	
Mourning Dove		x	x	
Nashville Warbler	x			
Ovenbird	x	x		
Pheasant			x	x
Orchard Oriole			x	
Osprey				x
Phoebe	x	x	x	x
Pileated Woodpecker	x			
Pied-Billed Grebe				x
Pine Warbler		x		

Continued

TABLE 58. Continued

SPECIES	White Pine-Hemlock-Northern Hardwood region	Yellow Pine-Hardwood Region	Orchards, fields pasture and cultivated land	Freshwater marshes
Prairie Warbler		x		
Red-Eyed Vireo	x	x		
Prairie Horned Lark			x	
Purple Martin			x	
Redstart	x	x		
Redtailed Hawk	x		x	
Red-shoulder Hawk			x	
Redwinged Blackbird			x	x
Robin		x	x	
Rosebreasted Grosbeak		x	x	
Ruffed Grouse	x	x		
Rough-Winged Swallow				x
Saw-Whet Owl	x			
Scarlet Tanager	x			
Savannah Sparrow			x	x
Screech Owl	x	x	x	
Short-Billed Marsh Wren				x
Sharp-Shinned Hawk	x		x	
Snipe				x
Song Sparrow		x	x	x
Sora				x
Sparrow Hawk	x		x	
Spotted Sandpiper				x
Starling			x	
Swamp Sparrow				x
Tree Swallow		x	x	x
Towhee		x		
Upland Plover			x	
Veery	x	x		
Vesper Sparrow			x	
Virginia Rail				x
Warbling Vireo			x	
Whip-Poor-Will	x	x		
White Breasted Nuthatch	x			

Continued

Continued

TABLE 58. Continued

SPECIES	White Pine-Hemlock-Northern Hardwood region	Yellow Pine-Hardwood Region	Orchards, fields pasture and cultivated land	Freshwater marshes
Woodcock			x	x
Wood Duck				x
Wood Pewee	x	x		
Wood Thrush	x		x	
Yellow-Billed Cuckoo			x	
Yellow-Throated Vireo			x	
Yellow Throat	x			x
Yellow Warbler		x	x	x
TOTAL NUMBER OF SPECIES	43	33	60	35

important habitats in the region. They are scattered throughout the eastern portion of the state and provide breeding areas for resident species as well as stopover points and wintering grounds for a number of migratory birds and waterfowl.

Bird census data, from 1966 through 1972 (U. S. Bureau of Sport Fisheries and Wildlife), for selected census areas in eastern Massachusetts are presented in Appendix H. Those birds which were sighted on an average of 20 or more times along a 25 mile transect have been diesgnated as "abundant" for purposes of the present discussion (Table 59). Twelve species are listed as abundant throughout the study area; four additional species are abundant only on Cape Cod. Habitat requirements of these species are presented in Appendix I. Of the twelve common inhabitants of the entire eastern portion of the state, seven are considered desirable species including: the chickadee, bluejay, catbird, robin, towhee, song sparrow and yellow throat. The common grackle, crow, house sparrow, redwinged blackbird and starling are often nuisance species in certain areas of the country.

Those species which averaged more than 5 but less than 20 sightings per transect during the sample years have been designated as "common to fairly common", (Table 60). Most of the species are encountered both in northeastern Massachusetts and on Cape Cod. However the barn swallow, house wren and wood thrush are uncommon to rare on the Cape and the mockingbird and pine warbler are uncommon to rare in northeastern Massachusetts.

c) <u>MAMMALS</u>

The most common mammals of northern Massachusetts and Cape Cod are presented in Table 61. Relative abundance of each species is given for Essex, Middlesex, Worcester and Barnstable counties. Relative abundances are an intragroup comparison. It should be noted that many species have fairly restricted habitats and thus while abundance within a county may be listed as common, distribution may be very localized.

White tail deer are practically the only large mammals in eastern Massachusetts. Deer are more numerous in Worcester county and Cape Cod than in Essex and Middlesex counties. Occasionally a moose or black bear may be found in the area but these individuals are transients and not permanent residents.

TABLE 59. LIST OF ABUNDANT BIRDS WHICH ARE FOUND IN TWO REGIONS OF EASTERN MASSACHUSETTS[1]

(from, U. S. Bureau of Sport Fisheries and Wildlife Bird Census Data, 1966 - 1972)

	LOCATION	
SPECIES	ESSEX, MIDDLESEX AND WORCESTER COUNTIES	CAPE COD
Baltimore Oriole		x
Black-Capped Chickadee	x	x
Blue-Jay	x	x
Bobwhite		x
Catbird	x	x
Chipping Sparrow		x
Common Grackle	x	x
Crow	x	x
House Sparrow	x	x
Mourning Dove		x
Redwinged Blackbird	x	x
Robin	x	x
Rufous-sided Towhee	x	x
Song Sparrow	x	x
Starling	x	x
Yellowthroat	x	x

[1] Mean number of individuals per transect during the sample period (1966-1972) is >20.

TABLE 60. LIST OF COMMON TO FAIRLY COMMON BIRDS WHICH ARE FOUND IN FOUR LOCATIONS IN EASTERN MASSACHUSETTS[1]

(from U. S. Bureau of Sport Fisheries and Wildlife Bird Census Data, 1966 - 1972)

SPECIES	LOCATION NORTHERN ESSEX COUNTY	MIDDLESEX-WORCESTER COUNTY AREA	EAST DENNIS (CAPE COD)	WELLFLEET, (CAPE COD)
American Goldfinch	x			x
Baltimore Oriole	x	x	**	**
Barn Swallow	x	x		
Brown-headed Cowbird	x			x
Chimney Swift	x	x	x	
Chipping Sparrow	x	x	**	**
Eastern Kingbird		x		x
House wren	x	x		
Ovenbird		x	x	
Mockingbird				x
Mourning Dove	x	x	**	**
Pine Warbler				x
Red-Eyed Vireo	x			x
Tree Swallow	x	x		x
Wood Thrush	x	x		
Yellow Warbler	x			x
Yellow-Shafted Flicker	x	x	x	x

** Abundant (see Table)

1 Mean number of individuals per transect during the sample period (1966 - 1972) is >5 - <20.

TABLE 61. MAMMALS OF NORTHEASTERN MASSACHUSETTS AND CAPE COD[1]

SPECIES	ABUNDANCE ESSEX	MIDDLESEX	WORCESTER	BARNSTABLE
Cervidae:				
whitetail deer	P	P	C	C
Leporidae:				
eastern cottontail	C	C	C	C
New England cottontail	C	C	C	P
Snowshoe hare	C	C	C	R
Mustelidae:				
striped skunk	C	C	C	C
short-tailed weasel	C	C	C	C
long-tailed weasel	C	C	C	C
mink	C	C	C	C
otter	P	P	C	C
fisher	R/A	R/A	R/A	R/A
Procyonidae:				
raccoon	C	C	C	C
Didelphiidae:				
opossum	P	P	C	P
Felidae:				
bobcat	C	C	C	C
Canidae:				
New England coyote	R/A	R/A	P	P
gray fox	C	C	C	C
red fox	C	C	C	C
Sciuridae:				
eastern gray squirrel	C	C	C	P
red squirrel	C	C	C	P
eastern chipmunk	C	C	C	C
woodchuck	C	C	C	C
northern flying squirrel	C	C	C	P
southern flying squirrel	C	C	C	C

Continued

TABLE 61. Continued

SPECIES	ESSEX	MIDDLESEX	WORCESTER	BARNSTABLE
	ABUNDANCE			
Castoridae:				
beaver	P[1]	P	C	R
Erethizontidae:				
porcupine	P	P	C	P
Cricetidae:				
deer mouse	A	A	C	A
white footed mouse	C	C	C	C
red backed vole	C	C	C	C
meadow vole	C	C	C	C
pine vole	C	C	C	C
muskrat	C	C	C	C
Zapodidae:				
meadow jumping mouse	C	C	C	C
woodland jumping mouse	C	C	C	C
Muridae:				
Norway rat	C	C	C	C
house mouse	C	C	C	C
Talipidae:				
eastern mole	C	C	C	C
hairytail mole	C	C	C	C
starnose mole	C	C	C	C
Soricidae:				
masked shrew	C	C	C	C
shorttail shrew	C	C	C	C
Vespertilionidae:				
little brown myotis	C	C	C	C
keen myotis	C	C	C	C
eastern pipistrel	C	C	C	C
big brown bat	C	C	C	C
silver haired bat	C	C	C	C
hoary bat	C	C	C	C
red bat	P	P	P	P

[1] P = present, status uncertain R = rare
C = common A = absent

The eastern cottontail is the most abundant rabbit throughout the region. However in wooded and upland areas the New England cottontail and snowshoe hare are common. Snowshoe hare are rarely found on Cape Cod.

The most common mustelid is the striped skunk. Weasel and mink are commonly found throughout the region. The otter is primarily restricted to Worcester county and Cape Cod. The fisher is a rare visitor to Massachusetts and sightings no doubt represent transient individuals.

The raccoon is commonly encountered throughout the area and is found wherever there are streams and lakes. The opossum is present in all four counties but is more abundant in Worcester county. Possums eat almost any kind of food and live in any place that will afford shelter.

Predators such as bobcats, gray and red fox are found throughout the region. While they are common mammals, local populations are never large. The New England coyote is increasing in abundance throughout the state but detailed knowledge about this species is sparse.

Members of the squirrel family are all commonly encountered throughout the region; however, numbers of red and gray squirrel and the northern flying squirrel are lower on Cape Cod.

Beaver, the largest North American rodent, is present throughout Massachusetts. Distribution is localized as they are restricted primarily to streams and lakes.

Porcupine are common residents especially in wooded areas with abundant rock outcroppings. They are more common in Worcester County than in the more eastern portion of the state.

In terms of numbers, rodents are by far the most important mammals in the region. Deer mice are common in Worcester County but are rarely found farther east. The white footed mouse is the most abundant truly forest species. Voles commonly occur throughout the study area. Muskrats are restricted in distribution to wetland areas and slow streams but are found in each county.

Both species of jumping mice occur in eastern Massachusetts although their distributions are very localized. These species are not as numerous as other rodents.

The Norway rat and house mouse are found in close association with man. While most frequently encountered near human habitation, they are also found in forested and agricultural areas during the warmer months.

Three species of moles occur in the region. The eastern mole is found in more open areas, the hairytailed mole in wooded areas and the star nose mole in wet areas.

Shrews occur throughout each county. The masked shrew is the most abundant mammal within the state and the shorttail shrew is second in abundance.

Seven species of bats are encountered throughout eastern Massachusetts. The little brown myotis and the big brown bat are the most numerous.

Habitat characteristics of the principal species of mammals are presented in Appendix J.

d) SOIL ORGANISMS

The following is a general discussion of the principal types of soil organisms and a brief reference about the types of processes in which they play an important role. This section pertains to a "generalized soil" and it must be remembered that considerable variations exist. Soil organisms include both microorganisms and macroorganisms. The primary soil microbes are: bacteria, actinomycetes, fungi, algae and protozoa. The principal macrofauna include earthworms, nematodes, mites and insects. Comparison of the abundance and biomass of the major groups of soil organisms is presented in Table 62.

In both agricultural and forest soils, the microbial population is concentrated in the organic-matter rich region at the soil surface. Numbers decrease rapidly with depth. One site of intensive microbial colonization is at the surface of plant roots. Roots and root hairs are almost fully coated by a film of microorganisms, which are 10-50 times more numerous there than in soil away from roots.

The bacteria are the smallest, most numerous and biochemically active group, especially where oxygen levels are low. It has been estimated that there are 10^9 bacteria per gram of soil, and the total number of bacteria in the top foot of one acre of fertile soil may weigh as much as 1000 pounds, or 0.03 percent of the weight of the soil. The

TABLE 62. RELATIVE ABUNDANCE AND BIOMASS OF THE PRINCIPAL SOIL ORGANISMS

ORGANISMS	ABUNDANCE	BIOMASS (lbs/acre-foot)
MICROORGANISMS		
Bacteria	10^9/gm. of soil	1000
Actinomycetes	10^6/gm. of soil	≈1000
Fungi	10^5/gm. of soil	≈2000
Algae	Very low	Very low
Protozoa	Very low	200
MACROORGANISMS		
Nematodes	Several millions/ft^3	50
Earthworms	Several million/acre	≈1000
Insects and Mites	Several billion/acre	

most prevalent form of soil bacteria are the rod-shape or bacillus forms. However, spherical, coccidial and spiral forms are also common. Soil bacteria are not distributed uniformly through the soil. Because they depend largely on organic matter they occur most abundantly near organic residues.

Bacteria that derive both carbon and energy from organic substances are called heterotrophic forms. A few species possess pigments that enable them to utilize energy in sunlight. They obtain carbon directly from the CO_2 in the atmosphere (as do green plants) and are thus both autotrophic and photosynthetic. Still other autotrophic forms are chemosynthetic; although they derive their carbon from the atmosphere, their energy is obtained from oxidation of simple chemical materials, not from sunlight.

Most bacteria depend on nitrogen which has previously been combined into mineral forms such as ammonium or nitrates or into organic nitrogen compounds such as plant and animal protein. A limited number are able to utilize the gaseous form of nitrogen in the atmosphere and are called nitrogen fixers. Those which utilize nitrogen in the air, in partnership with leguminous host plants, are called legume-nodule bacteria or rhizobia. There are also free living, chemosynthetic, nitrogen-fixing forms called Azotobacters, which occur in relatively small numbers. Some of the photosynthetic bacteria can also utilize atmospheric nitrogen.

The next most abundant group of soil organisms are the actinomycetes which are morphologically intermediate between bacteria and fungi. Actinomycetes are unicellular organisms and the individual cells are about the same size as bacteria in cross section. However, unlike bacteria they form long, threadlike, branched filaments. In most soils, the actinomycetes are only one-tenth as numerous as bacteria (10^6 individuals per gram of soil), but because their cells are much bigger, the total weight in an acre-foot of soil roughly equals that of bacteria. The actinomycetes usually constitute a greater fraction of the total microbial population in soils of low moisture content, and in organic material in the later stages of breakdown, than they do in wet soils or in residues in the initial stages of decomposition. Some thermophilic actinomycetes are prevalent in rotting manure, hay and compost.

The <u>fungi</u> are fewer in numbers (10^5 per gram of soil) than either the bacteria or the actinomycetes. Numerically they account for perhaps no more than one percent of the three microbial groups. However, they occupy more volume in the soil than any other group. In actual amount of cell substance, their total acre-weight roughly equals the combined acre weight of bacteria and actinomycetes. Many different species of fungi exist in the soil. Some are microscopic, such as yeasts and simple molds while others are large and complex such as mushrooms and bracket fungi. The sporulating structures of the larger species may be several inches wide at the surface.

Fungi have no chlorophyll and therefore must rely on organic materials for both a source of carbon and energy. Fungi are important in decay processes because they can initiate decomposition and grow vigorously once introduced. They can breakdown complex plant substance such as cellulose and lignin. Many species are parasitic on plants and animals. The absence of oxygen sharply limits the growth of nearly all fungi, thus they are relatively inactive in water-logged soil. The formation of peaty organic soils is due partly to the inability of fungi to grow under water-logged conditions. Under such conditions, many plant constituents escape decomposition and the accumulation of organic matter exceeds the rate of breakdown. Under many coniferous and mixed hardwood coniferous stands, the profuse penetration of fungi, and the formation of a strongly acidic organic layer at the surface, influence the development of podzolized soils.

Some fungi can colonize the surfaces of plant roots; some also penetrate root surfaces to form symbiotic associations known as mycorhizae. This fungal association causes the development of many short roots in pines and other trees. The superior absorption power of these roots is believed due to their much greater surface area, often exhibiting several hundred times more absorbing surface than nonmycorhized roots.

Algae are normally present in fewer numbers than other microorganisms and represent only a minor fraction of the total microbes in most soils. In very moist or flooded soils, dense surface growths of algae commonly occur. Most of the soil species live on the surface but some forms occur at greater depths. Those individuals which live below the surface use plant residues or soil organic matter as their food supply. Only in the presence of light can algae manufacture carbohydrates. Blue green algae can fix both atmospheric carbon dioxide and nitrogen. Algae at times are important in soil formation and in the initial colonization of some ground surfaces.

Protozoans and nematodes constitute a very large and diverse group of organisms. Protozoa are classified according to their modes of mobility. They are larger and more complex structurally than the bacteria but are much less numerous. It is estimated that fertile soils contain approximately 200 pounds of protozoa per acre-foot of soil. Their primary role in the soil appear to be consumption of bacteria. Nematodes are nonsegmented worms; most are microscopic or nearly so. A number of species parasitize plant roots and these have been intensively studied. Most species feed on soil microflora and protozoa while other species are predaceous or saprophytic. Nematodes may number several millions per cubic foot of soil; the total weight in an acre-foot of soil may be 50 pounds.

Earthworms, under favorable conditions, are the dominant animals in the soil. At such times their weight equals or exceeds that of all other soil-dwelling animals combined. They flourish in well-drained soils that contain abundant organic matter and a continuous supply of available calcium. Earthworms number several million to an acre in favorable soils with a total weight of approximately 1000 pounds.

Earthworms are important agents in mixing surface organic residues with the underlying soil. The earthworms contained in one acre can bring to the surface 20 tons of soil a year. Their activity is most intense in the top 6 inches although tunnels do extend to several feet in depth. Earthworm channeling improves soil aeration and increases movement of water into and through the profile. Earthworms are considered an indication of good soil fertility rather than its cause.

Mites and insects are present in soils in considerable numbers. Mites range in size from microscopic to barely visible. They occasionally reach populations of several billion per acre. Insect life in the soil is represented by many thousands of morphologically diverse species with varied life cycles and feeding habits. Springtails are the most numerous group, especially in forest soils. Insects affect soil structure, porosity and water intake rates, and carry on extensive soil transport.

Bacteria, actinomycetes and fungi are the soil organisms which have the greatest effect on soil ecology. Some workers suggest that the decomposer food chain is of greater importance in terms of energy flow than the grazing chain. It has been estimated that 90% of the energy flow through an ecosystem is accounted for by microorganisms (Phillipson, 1966).

Bacteria are primarily responsible for such important processes as nitrification, denitrification, nitrogen fixation and sulfur transformations. Fungi are good competitors for simple carbohydrates and bioproducts of the less efficient bacteria. The fungi are involved in humus formation, aggregate stabilization and certain mineral transformations. In addition, many of the plant diseases related to moist soil conditions are caused by fungi. The actinomycetes produce numerous antibiotics and are quite important to the pharmaceutical field. They are not as effective in the breakdown of some compounds as are the bacteria and fungi, but they compete more effectively on the more resistant organic compounds. Under certain conditions, such as flooded soils, algae play an important role in nitrogen-fixation. Protozoa, while being predators of soil bacteria, are not considered detrimental to soil ecology. Microbial processes, such as decay and nitrogen fixation, proceed as fast or even faster when protozoa are present as when they are absent. Nematodes, apart from their relationships with specific plants, have negligible impact on decay processes or soil characteristics.

Earthworms, insects and mites not only affect soil structure, porosity, aeration, mixing etc. but appear in some way to facilitate the activity of microbes. It is generally accepted that larger heterotrophs, by destroying litter mechanically, provide, in the form of food reamins and feces, smaller particles with a much greater surface area, which can be attacked more readily by microorganisms. It is not clear whether larger animals, in addition, alter the chemical composition of the litter. Some workers are of the opinion, according to Phillipson (1966), that soil animals not only fragment organic matter but also cause chemical changes that enable bacteria and fungi to decompose it further; however, others have shown that with certain species the humic components in the feces are little changed after passage through the gut.

Soil temperatures between 25 and 35°C are best for most soil microbes. Lower temperatures tend to lengthen life cycles and slow metabolism, while higher temperatures speed metabolism until temperature itself becomes limiting. A certain soil moisture level is required for microbial activity, but once moisture becomes too great oxygen diffusion is reduced. In order for microbes to thrive they need a source of energy, an electron acceptor and essential nutrients. Under aerobic conditions, oxygen is the electron acceptor but under anaerobic metabolism, nitrates, sulfates or organic compounds are the acceptors. Nitrogen and phosphorous are the nutrients which normally limit microbial growth but in some situations other nutrients can be limiting. Many microorganisms are sensitive to pH while many others are not greatly affected by a one-unit shift above or below the optimum. The most significant affect of pH on soils results from change in nutrient availability.

8. Productivity

Productivity of a specific terrestrial site is dependent to a large degree on the characteristics of the dominant soils which occupy that site. Production of grains, seed crops, grasses and legumes is substantially affected by the topography of the area and the degree of stoniness of the soils. Forest production, however, is little affected by these factors although timber harvesting activities and other forestry programs are more difficult on steeper rocky terrain. The suitability of the major soil series in the study area for production of agricultural and forest crops is presented in Appendix K.

Estimated productivity of the major soils for sweet and silage corn, hay, and forage is presented in Appendix L. Topography and degree of soil stoniness were not taken into account in this Appendix even though agricultural activities can be hampered or restricted entirely on steep, rocky slopes. Agricultural productivity in the subsequent discussions is based on moderately high levels of management which includes: 1) applying lime, manure and commercial fertilizer in adequate amounts; 2) using cropping systems and crop residues properly; 3) draining and irrigating if necessary; 4) controlling runoff and erosion; 5) controlling weeds, insects and plant diseases; 6) preparing seedbeds properly; 7) selecting suitable varieties. Pasture is improved by 1) fertilizing and liming; 2) controlling brush and weeds; and 3) seeding desirable forage mixtures.

Productivity of sweet corn (measured in bushels per acre) is based on the following categories: high: 200-300; moderate: 200-250; low: 75-80 and unsuited (production data for unsuitable soils is not available). Comparison of the major soil series for sweet corn production is presented below:

HIGH	MODERATE	LOW	NOT SUITED
Agawam	Charlton	Acton	Au Gres
Essex	Deerfield	Paxton	Buxton
Hadley	Enfield	Woodbridge	Carver

(CONTINUED)

(CONTINUED)

HIGH	MODERATE	LOW	NOT SUITED
Merrimac	Hinckley		Elmwood
Winooski	Ninigret		Hollis
	Scituate		Limerick
	Sudbury		Muck
	Sutton		Ridgebury
	Windsor		Saco
			Saugatuck
			Scarboro
			Swanton
			Walpole
			Whitman

Productivity of silage corn (measured in tons per acre) is based on the following categories: high: 16-22; moderate; 11-18; and low: 10. Comparison of silage corn productivity among the various soil series is presented below:

HIGH	MODERATE	LOW	NOT SUITED
Elmwood	Acton	Hinckley	Au Gres
Enfield	Agawam		Carver
Paxton	Buxton		Hollis
Woodbridge	Charlton		Limerick
Swanton	Deerfield		Muck
	Essex		Ridgebury
	Hadley		Saco
	Merrimac		Saugatuck
	Ninigret		Scarboro
	Scituate		Walpole
	Sudbury		Whitman
	Sutton		
	Winooski		

Productivity of silage corn and sweet corn are not necessarily mutually related. For example, those soils with the highest productivity for sweet corn were only moderately productive for silage corn. The soil series with highest productivity for silage corn were, with the exception of Enfield, either low in productivity or not suitable for sweet corn. With the excpetion of the Buxton, Elmwood and Swanton series, soils which were not suitable for sweet corn were also not suitable for silage corn.

Productivity of alfalfa and brome grass hay (measured in tons per acre) is based on the following categories: high: 4.5-

5.5; moderate: 3-4.5; and low: 3-3.5. Comparison of the various soils in terms of production of alfalfa-brome grass hay is presented below:

HIGH	MODERATE	LOW	NOT SUITED
Agawam	Acton	Deerfield	Au Gres
Charlton	Elmwood	Hinckley	Buxton
Hadley	Enfield	Scituate	Carver
Winooski	Essex	Windsor	Hollis
	Merrimac		Limerick
	Ninigret		Muck
	Paxton		Ridgebury
	Sudbury		Saco
	Sutton		Saugatuck
	Woodbridge		Scarboro
			Swanton
			Walpole
			Whitman

Productivity of timothy and clover hay (measured in tons per acre) is based on the following categories: high: 4-4.5; moderate: 3-4; and low: 1.5-3.5. Comparison of the various soils for production of timothy-clover hay is presented below:

HIGH	MODERATE	LOW	NOT SUITED
Acton	Agawam	Carver	Muck
Buxton	Au Gres	Hinckley	Saco
Charlton	Enfield	Hollis	
Deerfield	Paxton	Merrimac	
Elmwood	Scituate	Ridgebury	
Essex		Windsor	
Hadley			
Limerick			
Ninigret			
Saugatuck			
Sudbury			
Sutton			

Agawam, Charlton, Hadley and Winooski soils are highly productive for both hay crops. In addition, 12 other soils have high productivity for timothy-clover hay. A total of thirteen soil series are not suitable for production of alfalfa-brome grass hay. Of these, only two, Muck and Saco, are also unsuitable for timothy-clover hay.

Pasture productivity is measured in terms of cow acre days, i.e., the number of days that one acre of land will support one cow. Pasture productivity is based on the following categories: high: 220-250; moderate: 150-250; low: 150-170. Comparison of the various soils for production of forage is presented below:

HIGH	MODERATE	LOW	NOT SUITED
Acton	Agawam	Hinckley	Muck
Buxton	Au Gres	Hollis	Saco
Deerfield	Carver	Saugatuck	
Elmwood	Charlton	Scarboro	
Enfield	Essex	Whitman	
Ninigret	Hadley		
Paxton	Limerick		
Sudbury	Merrimac		
Winooski	Ridgebury		
Woodbridge	Scituate		
	Sutton		
	Swanton		
	Walpole		
	Windsor		

Most of the soils are rated in the high and moderate categories for forage production. Those soils which are low in pasture productivity were also low in productivity or unsuitable for hay crops.

Soils influence the development and management of woodlands, affecting the growth as well as the distribuiton of tree species and forest types. Forest productivity of a soil is measured by site index, a term which denotes the average height of the dominant and co-dominant trees in a fully stocked stand at the age of 50 years. Productivity on a specific soil will vary with the intensity of management. In this discussion, forest stands are assumed to be unmanaged. Productivity (measured by site index range) for northern hardwoods, upland oaks, white pine and red pine is presented in Appendix M.

Comparison of the site index ranges of various soils for the production of northern hardwoods is presented below:

58+	52-57	46-51	45-
Paxton	Acton	Hinckley	Carver
Ridgebury	Buxton	Hollis (extremely rocky)	Muck
Winooski	Charlton		Saco

CONTINUED

CONTINUED

58+	52-57	46-51	45-
Woodbridge	Deerfield	Limerick	Scarboro
	Elmwood	Saugatuck	Whitman
	Essex	Swanton	
	Hadley	Walpole	
	Hollis (very rocky)	Windsor	
	Merrimac		
	Ninigret		
	Scituate		
	Sudbury		
	Sutton		

The site index range on Agawam soils is 45-64, indicating considerable variability exists in the height of northern hardwoods growing on this soil series.

Comparison of the site index ranges of various soils for production of upland oaks is presented below:

65+	55-64	45-54	44	Not Suited
Paxton	Acton	Enfield		Muck
Ridgebury	Au Gres	Hinckley		Saco
Winooski	Buxton	Hollis		Scarboro
Woodbridge	Charlton*	Merrimac		Whitman
	Deerfield	Saugatuck		
	Elmwood	Windsor		
	Essex*			
	Hadley*			
	Limerick			
	Ninigret*			
	Scituate*			
	Sudbury			
	Sutton*			
	Swanton			
	Walpole			

*Site index range quite variable

The site index range for upland oaks growing on Charlton, Essex, Hadley, Ninigret, Scituate and Sutton soils is 55 or greater.

Paxton, Ridgebury, Winooski and Woodbridge soils produce the best growth responses for both northern hardwoods and upland oaks. Growth of the important deciduous trees is slow on Carver soils. Northern hardwoods grow poorly on Muck, Saco, Scarboro and Whitman soils; these soils are not suitable for upland oaks. Most of the soils have an intermediate site index range for both northern hardwoods and upland oaks.

Comparison of the site index ranges of various soils for white pine and red pine is presented below:

WHITE PINE

70+	60-69	50-59	49-
Elmwood	Acton	Deerfield	Carver
Ridgebury	Agawam	Hinckley	
Winooski	Au Gres	Hollis	
Woodbridge	Buxton	Muck	
	Charlton	Saco	
	Enfield	Scarboro	
	Essex	Sudbury	
	Hadley	Whitman	
	Limerick	Windsor	
	Merrimac		
	Ninigret		
	Paxton		
	Saugatuck		
	Scituate		
	Sutton		
	Swanton		
	Walpole		

RED PINE

70+	60-69	50-59	49-	NOT SUITED
Au Gres	Buxton	Agawam	Carver	Muck
Enfield	Charlton	Hinckley		Saco
Limerick	Deerfield	Hollis		Scarboro
Ridgebury	Essex	Merrimac		Whitman
Swanton	Hadley	Saugatuck		
Walpole	Ninigret	Windsor		
Winooski	Scituate			
	Sudbury			
	Sutton			

White pine and red pine do well on a wide variety of soils. Ridgebury and Winooski soils produce the best growth responses for each species and both grow very slowly on the Carver series. These pines have moderate growth responses on many of the same soils except for Au Gres, Enfield, Limerick, Swanton and Walpole, which produce rapid growth of red pine; and Muck, Saco, Scarboro and Whitman, which are unsuitable for red pine. Site index data are not available for red pine growing on Acton, Elmwood, Paxton and Woodbridge soils.

Expected average annual growth and volume per acre of mature (50 years of age) unmanaged, fully stocked stands of northern hardwoods, upland oaks, white pine and red pine in relation to site index is shown in the table below (U. S. Soil Conservation Service, 1967):

FOREST TYPE OR SPECIES	SITE INDEX	CORDS		BOARD FEET (INTERNATIONAL 1/4-INCH RULE)	
		ANNUAL GROWTH	TOTAL VOLUME	ANNUAL GROWTH	TOTAL VOLUME
Northern hardwoods	60	0.62	31	60	3,000
	55	.53	27	46	2,300
	49	.44	22	32	1,600
	43	.37	18	[1]	[1]
Upland Oaks	70	.70	35	200	10,000
	60	.50	25	125	6,250
	50	.40	20	65	3,250
	40	.20	10	30	1,500
White pine	75	1.96	98	740	37,000
	65	1.56	78	560	28,000
	55	1.16	58	360	18,000
	45	.76	38	180	9,000
Red pine	75	2.56	128	1,020	51,000
	65	1.98	99	760	38,000
	55	1.40	70	460	23,000
	45	1.08	54	340	17,000

[1] Generally not worth managing for lumber

In terms of cordwood and board feet (lumber), coniferous stands at maturity are considerably more productive than are deciduous stands. Red pine is the most productive species followed by white pine. Upland oak stands are higher in lumber production than are the northern hardwoods. Differences between deciduous stands for cordwood production are minimal.

9. Assumptions and Critical Information

a) WASTEWATER COMPOSITION

Composition of proposed secondary-treated wastewaters for the Merrimack River Basin in Massachusetts including a comparison with Environmental Protection Agency (EPA) requirements for irrigation water, public and livestock drinking water supplies is presented in Table 63. Those parameters, which approach or exceed the EPA requirements, will be discussed below in detail.

1) NUTRIENTS

In discussing terrestrial wastewater management it is necessary to consider the nutrients, nitrogen and phosphorus, as a special category. These are an obvious agricultural benefit and accordingly are not limited by irrigation water standards. Only nitrates appear in drinking water standards since high concentrations can cause infant methemoglobinemia (an oxygen deficiency in the blood).

Both nitrogen and phosphorous have been identified as major causative agents in the eutrophication of natural surface water bodies. Both can be phototoxic in very high concentrations. High nitrate levels in plants may be toxic to animals which feed on them.

2) PHENOLS

Phenols are limited in drinking water standards because they cause odor problems at low concentrations, and in conjunciton with chlorination processes may form chlorophenols which are odor detectable at much lower

TABLE 63. COMPOSITION OF PROPOSED SECONDARY-TREATED WASTEWATERS COMPARED WITH EPA REQUIREMENTS FOR IRRIGATION WATER, PUBLIC WATER SUPPLY AND LIVESTOCK DRINKING WATER[1]

COMPOSITION OF SECONDARY-TREATED WASTEWATER		EPA IRRIGATION WATER	EPA PUBLIC WATER SUPPLY	EPA LIVESTOCK WATER
Oxygen Demanding Compounds:				
BOD	30	no limit	------	no limit
COD	70			
Biostimulants:				
Total Nitrogen	20			
Organic Nitrogen (TKN)	2.0			
Ammonium (NH_4^+)	10	------	0.5	------
Nitrite (NO_2)	0.0	no limit	1.0	10
Nitrate (NO_3^-)	8.0	no limit	10	100 (NO_3 + NO_2)
Total Phosphorus	13	------	no limit	
Other Organic Compounds:				
Phenols	0.3	------	0.0001	
Refractory Organics (COD-BOD)	40			
Cyanide	?		0.2	------

Continued

TABLE 63. Continued

COMPOSITION OF SECONDARY-TREATED WASTEWATER		EPA IRRIGATION WATER	EPA PUBLIC WATER SUPPLY	EPA LIVESTOCK WATER
<u>Inorganics:</u>				
(Metals)				
Ag	?	------	0.05	------
Al	?	5.0	------	5.0
As	?	0.10	0.1	0.2
Cd	0.1	0.01	0.01	0.05
Cr	0.2	0.1	0.05	1.0
Cu	0.1	0.2	1.0	0.5
Fe	0.1	5.0	0.3	no limit
Hg	0.005	------	0.002	.001
Mg	17	------	------	
Mn	0.2	0.2	0.05	no limit
Na	40	no limit	no limit	------
Ni	0.2	0.2	no limit	------
Pb	0.1	5.0	0.05	0.1
Zn	0.2	------	5.0	25.0
(Non Metals)				
B	0.7	0.75	1.0	5.0
Cl^-	100	no limit	250	
$SO_4^=$	42	------	250	------
Ca	40			
Suspended Solids:	30	no limit	minimized	------
pH	7.0	4.5 - 9.0	5 - 9	------

1 Concentrations are in mg/l unless noted otherwise.

concentrations than other phenols. Phenols in high concentration can be toxic to organisms, especially in the case of sudden shock loads.

3) HEAVY METALS

Cadmium and chromium exceed requirements for irrigation waters; copper, manganese and nickel are found in concentrations at or near the maximum limits for water to be used for plant irrigation. Cadmium, chromium, mercury, manganese, and lead exceed limits for public water supplies. Cadmium, mercury, and lead either approach or exceed the maximum levels for livestock drinking water.

Concentrations of arsenic and silver are not known for the anticipated secondary quality wastewaters. Since EPA requirements for these metals are rather stringent for public water supplies, livestock drinking water and irrigation water, they will also be discussed.

Cadmium is an important constituent of wastewater because of its extremely high toxicity to both humans and animals. A FWPCA publication (1968) indicates that stringent drinking water standards are set because cadmium is a cumulative poison which results in an insidious, progressive chronic poisoning of the organism that ingests it. Schroeder (1964, 1965) indicated that this element is linked with arterial hypertension in both rats and also possibly in humans. Moreover, very low cadmium concentrations in milk have been correlated with cardiovascular death rates among people in the United States (Pinkerton and Murthy, 1969).

Cadmium according to recent research, is not an essential element. Cadmium is similar to zinc in its reaction with soils and uptake with plants. Research has shown that yields of some crops were reduced 25-50% by cadmium concentrations between 0.1-1.0 ppm in nutrient solutions. Certain species of plants absorb cadmium readily.

Chromium like cadmium is also an important wastewater constituent because of its potential adverse effects on humans. Chromium, in its various valence states, is toxic to man, in high concentrations. It has been related to lung tumors when inhaled and skin sensitizations. However, low levels are relatively non-toxic since small amounts are rapidly eliminated from the human body. While chromium has not been proven essential for human nutrition, it may be involved in the metabolism of fatty acids and insulin (Browning, 1969).

Chromium has been shown to cause toxicities to a number of plant species at concentrations of 1 to 5 ppm in nutrient solutions. Chromium concentrations of 5 ppm have produced iron deficiencies in some plants.

Copper and chemical compounds of copper are quite toxic in nature. Although copper is an essential and beneficial element in human metabolism, excessive amounts may produce emsis and liver damage. Since, normal diets barely provide adequate amounts of copper, small amounts are desirable in drinking water. Excessive levels can cause taste and corrosion problems in public water supplies.

While copper is essential to plant metabolism, excessive concentrations can be phytotoxic. Copper concentrations of 0.1 to 1.0 ppm in nutrient solutions have been shown to be toxic to a large number of plants. Copper retards photosynthesis of algae by penetrating the cell plasma and rupturing cell membranes. In higher plants copper suppresses development of fibrous roots and crop yields. At about 0.5 ppm of copper in water, plant growth is reduced and at slightly higher concentrations it causes chlorosis. Applications of only 10 lbs per acre of copper sulfate have retarded plant growth on sandy soils.

Mercury is not an essential element for nutrition of either humans or animals and its physiological role, if any, is unknown. Mercury is an important constituent of wastewaters due to its extreme and cumulative toxicity to humans, other animals and long term accumulation in the ecosystem. All of the organic forms of mercury (alkoxy, alkyl and aryl) are toxic, but the alkyl form is the most toxic to organisms. Moderately toxic inorganic mercury is converted to highly toxic and biologically mobile methylmercury by selected microbes. The accumulation and retention of these mercurials in the nervous system, the ease of their transmittal across the placenta, and their effect on developing tissue make them particularly dangerous. The lowest whole blood concentrations associated with toxic symptoms is 0.2 ppm.

Mercury, in excessive concentrations, can interfere with plant transpiration. Studies of algae metabolism showed that excessive mercury prevented cell division. Treatment of plant foliage may result in high mercury levels in crops.

Manganese is essential for the nutrition of both animals and plants; its salts are toxic only at very high dosages. Manganese concentrations must be limited in drinking water to prevent aesthetic and economic problems and to avoid possible physiological effects due to excessive intake by humans. Manganese is reported to affect the taste of drinking water at levels as low as 0.05 ppm and to stain laundry at 0.1 ppm.

Manganese concentrations at a few tenths to a few milligrams per liter in nutrient solutions are toxic to a number of crops. Symptoms of manganese toxicity vary but in general there is a crinkling of the leaf margin where the highest concentration accumulates. Grasmanis and Leeper (1966) found that trees which have once accumulated manganese are slow to lose its store. Even three years after soil liming, the symptoms of toxicity persisted, though in a progressively less severe form.

Nickel concentrations in solution cultures at 0.5 to 1.0 ppm have proven toxic to plants. Investigation of nickel in soils have shown that it is toxic to plants at the relatively low concentration of 40 ppm. Plants are less tolerant to nickel than to lead. Nickel and iron are antagonistic in the nutrition of certain plants.

Lead, in trace levels, is a natural component of both plant and animal life although it must be considered an extremely toxic substance. Acute toxicity is most common in children and is manifested by anorexia, vomiting and convulsing due to intracranial pressure. Chronic toxicity symptoms are anemia, weakness and weight loss in children and gastrointestinal and central nervous system complaints by adults. It is reported that with a lead intake of 0.6 mg per day, development of lead intoxication by humans is unlikely. Review of existing literature indicated that for livestock the toxicity of this element has not been established from a quantitative standpoint. There is agreement, however, that 0.5 ppm of lead in livestock drinking water is considered safe.

The phytotoxicity of lead is relatively low. Since soluble lead contents in soils are usually from 0.05 to

5.0 ppm little toxicity can be expected. Lead has been implicated as an inhibitor of cell division and is antagonistic to calcium metabolism. Some plants adjacent to highways have shown lead concentrations as high as 98 ppm, concentrations which are high enough to cause detrimental effects on the plants. MacLean *et al.*, (1969) concluded that lead in perennial rye grass was approximately 4 ppt regardless of whether the water supply contained lead or not. High concentrations in plants could be harmful to animals which feed on these contaminated plants.

Arsenic is toxic to both man and animals. Severe poisoning can result from 100 mg; 130 mg has proven fatal. Arsenic can accumulate in the body faster than it is excreted and can build to toxic levels from small amounts taken in periodically. Arsenic toxicity to animal life depends on its chemical form. Its organic oxides are considerably more toxic than the organic forms which occur in living tissues. Differences in toxicities of the various forms are clearly related to the rate of their excretion, the least toxic being the most rapidly eliminated. Except in unusual cases, arsenic normally occurs in waters as inorganic oxides. The acute toxicity of inorganic arsenic for farm animals ranges from 0.05 to 30.0 g per animal depending on the size and particular species.

Arsenic is also toxic to plants appearing to interfere with plant respiration. Some species can tolerate high levels of arsenic and others show toxicity symptoms at concentrations of 1 ppm. The amounts of arsenate that produce toxicity in sensitive plants vary from 100 lbs/acre for sandy soil to 300 lbs/acre for clay soils. Not much is known about plant uptake of arsenic from the soil. Possible leaching from the soil and reversion to less soluble and less toxic forms of arsenic will allow extensions in the time required for phytotoxicity. Although arsenic concentration may be increased in plants, there is little danger of animal toxicity. The effect of arsenic toxicity on plants is such that growth is limited before large amounts are absorbed and translocated to the plant top.

Silver is not considered an essential element for either plant or animal nutrition and is not normally found in animal or human tissues. Silver and its salts are moderately toxic. Concentration restrictions for public water supplies are for cosmetic rather than health considerations. Excessive levels cause a rather unsightly but apparently unharmful condition known as argyria in which a gray discoloration of skin, eyes and mucous membranes occur. Any amount over 1 gram of silver in the human body will result in this condition. There is little additional information on the toxicity of silver to humans. Silver is toxic to aquatic life, and lethal concentrations in the range of 4 to 50 ppb have been reported.

4) BORON

Boron concentrations in the secondary effluent approach the maximum limitation for irrigation waters. Boron has a relatively low toxicity to man and other animals. It has been reported that a concentration of 30 mg/l is not harmful to man.

Boron, however, is very toxic to many terrestrial plants. While boron is an essential element for the growth of plants, concentrations of 1 ppm are toxic to a number of sensitive species. Rates of boron accumulation vary widely between species. While, alfalfa can tolerate boron, many cereals and grasses and certain legumes are very sensitive to high levels. Sensitive crops show toxicities to boron at 1 ppm or less, semi-tolerant crops at 1 to 2 ppm and tolerant crops at 2 to 4 ppm. At boron concentrations above 4 ppm, irrigation water is generally unsatisfactory for most crops. Toxicity symptoms show up in the leaves. Boron apparently moves passively in the transpiration stream and, as water is lost through transpiration, boron is concentrated in the leaf.

b) SLUDGES

Composition of sludges from primary and secondary wastewater treatment processes is shown in Table 64. The ultimate fate of sludges from wastewater treatment processes will be finalized at a later date but will probably involve incineration. The ash content ranges between 20-40 percent of the dry solids content of the original sludge. A more thorough discussion of sludges and sludge generation can be found in Appendix III - Design and Costs.

TABLE 64. QUANTITY AND QUALITY OF SLUDGES FROM PRIMARY AND SECONDARY TREATMENT

(Metals)	Pounds/MGD	Pounds/Yr.[1]
As	2.3	839
Ca	9.4	3,431
Cd	0.5	182
Cr	5.3	1,934
Cu	3.0	1,095
Fe	47.0	17,155
Hg	0.01	3.6
K	3.0	1,095
Mg	16.8	6,132
Mn	1.1	402
Na	7.6	2,774
Ni	0.9	328
Pb	2.2	803
Se		
Zn	10.5	3,832
Al	12.8	4,672
(Non-Metals)		
B	0.6	219
Cl^-		
F^-		
$SO_4^=$		
S	7.3	2,664
(Nutrients)		
P	18.5	6,752
N	86.0	31,390

[1] Number of pounds produced per year based on 365 days of wastewater treatment.

c) EVALUATIVE CRITERIA

For the New England region, two basic techniques of land disposal of secondary-treated wastewaters were considered: spray irrigation (SI) and rapid infiltration (RI). Spray irrigation is defined as the controlled spraying of liquid wastewaters onto the land, at a rate measured in inches per week, with the flow path being infiltration and percolation within the boundaries of the disposal site. Rapid infiltration is defined as the controlled discharge, by flooding or other means, of liquid onto the land, at a rate measured in gallons per square foot per day, with the flow path being high rate infiltration and percolation.

In any location the environmental impact of added wastewater will vary directly with the total area in the drainage being affected. Each method of wastewater disposal can add an equal amount of total water. The difference is that SI applies wastewater at reduced rates over much larger areas of the watershed, while RI concentrates the point of application of effluent but nonetheless contributes an equal volume of water.

Land disposal of wastewaters requires an evaluation of impacts to natural ecosystems. Effects of wastewater disposal on climate, physiography, soils, groundwater, and flora and fauna must be determined in order to avoid significant disruption of existing biological communities. The interaction between various ecological parameters with the constituents in the applied wastewaters will determine the effectiveness of terrestrial ecosystems in providing the necessary renovation.

The following discussion is concerned with the effects of spray irrigation and rapid infiltration of secondary treated wastewaters on the previously listed environmental parameters and concurrently the role of each in the renovaation process. Distinction between the techniques, SI and RI, are made when appropriate. Regional vs. local impacts are also distinguished.

1) CLIMATE

The principal effects of climate on terrestrial wastewater management programs occur during periods of freezing temperatures (ground and air), intense precipitation and high winds. Any combination of freezing air temperatures, frozen ground and the presence of snow and ice can result in ice formation from at least a part of the applied liquid. Frozen surfaces reduce the infiltration capacity of the site which can lead to ponding and/or runoff that may eventually cause severe soil erosion. Impairment of groundwater quality may also occur during winter application periods, since the metabolic processes of plants, microorganisms and other life forms, as well as the purely chemical reactions in the soil column are inhibited. These processes are absolutely essential in providing the necessary renovation of the applied wastewaters.

Restrictions to wastewater application are necessary even during the warm months. Wastewaters should not be disposed of during periods of intense rainfall or when the soils are saturated with water. Infiltration and permeability rates are greatly reduced during such times, and wastewater runoff may occur. Soil saturation results in partial or complete anaerobic conditions and many of the biochemical reactions, which remove wastewater contaminants, are substantially reduced or curtailed entirely during these times.

Spray irrigation should not be undertaken during periods of intense winds, since aerosol losses are likely to occur. This could result in dissemination of wastewater droplets which could be carriers of pathogenic organisms as well as unpleasant odors. Even though chlorination of wastewaters deactivates most of the coliform bacteria, infectious viruses may still survive. While this risk applies equally to aquatic disposal techniques it seems prudent to avoid or minimize airborne losses of wastewater aerosols.

Climatological changes from rapid infiltration programs will be negligible. Unless extensive areas are involved in spray irrigation programs (an unlikely proposition), climatic effects of wastewater application on a region-wide basis will not occur. The most likely climatological impacts will take place within the SI sites themselves, primarily as a result of vegetational changes. Additions of wastewaters will cause less dramatic climatic changes in agricultural ecosystems than in forest stands.

Spray irrigation will result in higher humidity as a result of increased rates of evapotranspiration. Changes in air temperature will be directly influenced by the temperature of the applied wastewater. Indirectly, temperature may be decreased due to the increased evaporative processes which may reduce maximum air temperatures by 15° to 20°F (Driver *et al.*, 1972). Since water has a very high specific heat and will absorb large quantities of incoming radiation with little change in temperature, it will tend to moderate temperature maxima. In a similar manner the stored heat will be released during cool periods to maintain higher minimum temperatures.

Substantial climatic modification to the interior of mixed forest stands would result from the above mentioned processes, but primarily from changes in the forest canopy. Increased levels of nutrients and water would likely result in an increase in the percent cover and density of the tree canopy. The net result would be an increase in the interception and evaporative loss of precipitation and insulation from strong winds and solar radiation during the growing season. This would lead to a stable, cool, and humid climate within the interior of the stand. Such a condition may prevail on a year-round basis within coniferous stands.

2) PHYSIOGRAPHY

The major effect of topography upon terrestrial wastewater management operations is concerned with the infiltration and percolation capabilities of the soil. Soil drainage depends on topography as well as the textural characterization of the soil profile itself. Renovation for both SI and RI is accomplished within the soil complex, and it is essential that wastewaters infiltrate the soil and not run off the site.

On deep, very well drained soils, suitable for RI operations, runoff should not be a problem except on very steep slopes. The major constraint on SI sites is the prevention of surface water movement and soil erosion before infiltration can take place. In practice, most steeply sloped SI operations (slopes in excess of a 20 percent grade) are forested and the natural forest litter should be quite effective in preventing surface runoff and soil erosion. Operating agricultural sites are either flat or at most gently sloping to permit operation of conventional farm equipment.

The primary modification of existing topographic features from application of wastewaters would result from excessive soil erosion. Uncontrolled runoff and soil erosion must be prevented for legal and practical as well as ecological reasons. Removal of topsoils could also seriously impair the renovation potential of the site. The organic-rich surface layer is the most biochemically active of all soil horizons. Destruction of this layer would substantially hinder soil removal of pollutants, disrupt populations of soil microorganisms, and reduce the suitability for plant growth.

Careful selection of the proper soil, vegetative cover, surface relief, and modification of application rates during certain periods of time (heavy rains, frozen ground, high watertables, dormant vegetation, etc.) will result in little if any soil movement.

3) SOILS

A stable, aerobic soil ecosystem is an indispensable component of a land renovation site. Removal of wastewater contaminants is accomplished by physical and chemical processes which include filtration, ion exchange, adsorption, precipitation, chemical alteration and chelation. A given constituent of the wastewater may be involved simultaneously in several of these processes. Spray irrigation and rapid infiltration each utilize combinations of the above to achieve renovation.

Soils are mixtures of mineral particles, organic material, air and water. The pore space occupied by air or water may be as much as 50 percent of the total volume. The pathway through these pores is a maze of varying sized channels. It is the size distribution and the nature of this maze which controls the ability of the soil to filter out suspended solids that are found in wastewater. In most soils, the pore size distribution and the nature of the water-movement channels are such that suspended solids are completely removed after short travel distances.

Ion exchange is related to characteristics of both the clay fraction and organic matter. Although ion exchange is most directly related to dissolved cations, under certain circumstances soils have a limited capacity to retain anions by this mechanism. Layered aluminum silicate minerals in the clay fraction are largely responsible for the cation exchange capacity (CEC) attributed to the inorganic phase of soils. In many soils organic matter is as significant as the mineral phase in determining cation exchange capacity. This is particularly true of the surface horizons. On a unit weight basis the organic fraction can contribute more than the clay fraction to the total CEC of a soil.

Cation exchange capacity should not be equated to the capacity of a soil to remove chemicals from wastewater. Since the CEC of a soil is already saturated with common cations, retention of wastewater chemicals will be accompanied by the release of these cations into solution. The net effect will be some readjustment in the composition of the exchange and solution phases but the total soluble salt concentration in the wastewater will remain fairly constant.

Adsorption is the capacity of soils to retain dissolved chemicals so tightly that they can only be removed from the solid fraction with difficulty. This is the most important process by which chemicals are removed from wastewater. It is responsible for the high capacity of soils to retain anions such as phosphates as well as heavy metal cations.

Precipitation is the process whereby concentrations of cations and anions in the soil solution unite to form chemical compounds with a limited solubility. The concentration levels at which precipitation will begin to occur depend upon the individual compound in question.

During many biochemical and chemical reactions, the properties of chemical constituents are markedly altered by the transfer of electrons, a process known as oxidation/reduction. The presence or absence of oxygen is a prime factor in considering the importance of oxidation/reduction reactions in the soil.

As a consequence of various biochemical processes in the soil, some of the organic constituents become soluble in the soil solution. These soluble organics have the same chemical groups as those active in ion exchange and ion adsorption processes. These organics react with heavy metal cations to form chelates. The significance of these chelates lies in the fact that a new chemical has been formed, one which does not behave chemically as the same type of cation in uncomplexed form. The formation of soluble complexes reduces the ability of the soil to retain certain types of chemicals. However, many soluble chelates are available as plant nutrients, and the net effect may enhance the removal of chemicals from soil during cropping of wastewater renovation sites.

A considerable volume of information is available which is relevant to understanding the fate of wastewater constituents in soils. One fundamental problem is to determine the identity of chemicals in the wastewater and in the soil solution. Each form behaves differently and ultimate removal may well depend on its chemical nature. Reactions of wastewater chemicals in the soil are discussed in relation to RI and SI operations.

Secondary effluent from properly operating treatment plants contains relatively low levels of organic compounds. A portion of these organics are relatively easily degraded compounds and the biochemical oxygen demand (BOD) is accepted as an index of their presence. The remainder of the organic compounds are called refractory organics and these are degraded more slowly. Physical entrapment and chemical adsorption should provide the necessary retention time for effective microbial degradation of BOD and refractory organics at both RI and SI sites (Reed, 1972; Sopper and Kardos, 1973). Very little information however, is currently available on the rate at which organic compounds are actually decomposed in the soil.

Soils actively respond to inputs of nitrogen depending primarily upon its form. Organic nitrogen and ammonium nitrogen are held by the exchange sites of the soil (primarily by the clay minerals) and are also temporarily adsorbed by the soil particles themsleves. Generally, medium to heavy textured soils suitable for SI will effectively remove a significant fraction of the ammonium from solution.

A portion of the complexed ammonium is retained in a form available for plant uptake. That portion not utilized by plants is acted upon by aerobic microbes which oxidize them to nitrites and finally nitrates. Although nitrate is subject to temporary immobilization by soil microbes, the vegetative components provide the principal removal pathway. That portion of the nitrate which is not removed by plants becomes incorporated in the groundwater since soils have little capacity for fixation.

Once the nitrate passes the root zone there is only one remaining opportunity for its removal. Under anaerobic conditions, certain soil microbes can reduce nitrates to gaseous (elemental) nitrogen which then escapes into the atmosphere. This anaerobic pathway can provide significant nitrogen removal, but prolonged periods of anaerobiosis in the soil can cause extensive disruption to populations of other soil fauna and to plants, as well as adversely effect soil morphology.

The major components of terrestrial ecosystems responsible for phosphorus removal are fixation by the soil matrix and uptake by plants. Total phosphorus in wastewaters occurs in a number of forms but all are degraded to orthophosphate within the soil complex. Although phosphorus will also enter stabilizing reactions with soil organics, these are of minor importance. Plant removal will tend to maintain the retention capacity of the soil.

Phosphates are retained strongly by soils suitable for SI operations, i.e., those containing clay minerals and iron and aluminum hydrous oxides. At RI sites, retention of phosphates can occur but removal under conditions of heavy wastewater application on light textured soils may prove inadequate, with substantial quantities leaching through the system.

The exact quantity of phosphorus that can be adsorbed by soils is a matter of some debate. Most of the world's soils are deficient in phosphorus and many have a very high capacity to fix this element. Phosphorus must be added to agricultural lands each year as it is continually precipitated (made less soluble) by iron, aluminum and calcium. It may require up to 50 years before the precipitating agents are satisfied and the supply of phosphorus becomes readily available. Research has shown that some soils can regenerate their capacity to fix phosphorus when once saturated, if allowed to "rest" for a period of time. It is not known if a soil can go through more than one cycle of regeneration.

Magnesium (Mg^{++}) and sodium (Na^{+}) are the most abundant of all the cations in both wastewaters and in the soil. Neither are adsorbed by soils but they do participate in normal cation exchange processes. Thus when wastewater is added to a soil, the cations within each phase will be exchanged. The net result is that the composition of the solution will adjust somewhat but the total soluble salt content will remain about constant. This is true for both SI and RI operations. However, the composition of the exchange complex of most humid region soils will tend to accumulate more Na^+.

The significance of this applies mainly to SI sites where the soil contains montmorillonite type minerals in the clay fraction. As the percentage of exchangeable Na^+ increases, decreased soil permeability may result due to swelling of the clay minerals. The tendency for this to occur can be estimated from the sodium adsorption ratio (SAR) of the wastewater. In practice, long term application of wastewater to fine textural soils could result in decreased drainage if the SAR value exceeds 15. The ratio for most wastewaters is usually less than 15 (CRREL, 1972).

<u>Aluminum</u> (Al) is probably present in wastewaters in the form of colloidal hydroxide precipitates. For both SI and RI sites, Al will be effectively filtered by the soil matrix.

<u>Iron</u> (Fe) and <u>manganese</u> (Mn) are present in wastewater in association with organic matter or as suspended colloidal precipitates. When applied to soil, suspended Fe and Mn solids as well as much of the organically bound forms will be filtered. There may be some movement of soluble organic metal chelates, however the amounts of soluble Fe and Mn which remain in soil solution will be extremely small under aerobic conditions due to precipitation and adsorption. Thus under proper site conditions, SI and RI should effectively remove Fe and Mn from wastewater.

<u>Heavy metals</u> (Ag, As, Pb, Hg, Cd, Cu, Cr, Ni, Zn) are present in wastewaters as individual cations as well as in association with organic matter both in suspension and in the form of soluble organo-metallic complexes. It appears that under proper site conditions retention by the surface soil prevents significant movement of heavy metals to lower horizons for many years. This is true for even light textured sandy-loam soils with organic matter, provided that the pH is maintained near 7.0.

It is probable that heavy metals will be retained by the soil complex of SI sites. Maintenance of a near neutral pH in combination with additions of organic matter should prevent phytotoxicity problems from occurring. For RI sites, the effectiveness will depend on specific site conditions. Because of the high loading and very permeable soils associated with RI sites, it should be assumed that metals will accompany the flow of groundwater (CRREL, 1972).

Boron (B) is retained to some degree by soils with a high clay content and a high pH, however retention is not significant. Plants provide the only long-term removal. Bahr (1972) assumes that the soil solution will be at equilibrium with the boron added in wastewater by the end of the first 35 weeks of application. In addition, after the first year of applying wastewater, boron will essentially be moving out in the drainage water at a concentration equal to or greater than that which is applied depending upon evaporation and evapotranspiration rates.

Chlorides (Cl^-) and sulfates ($SO_4^=$) are normally present in relatively large amounts in wastewaters as anions of soluble salts. Cyanides (CN^-) occasionally occur. Of these anions, Cl^- and CN^- are not adsorbed by soils and will accompany the flow of wastewater through the profile regardless of the mode of application. Sulfates are adsorbed weakly by hydrous iron oxides. For SI operations, there will be some retention of $SO_4^=$ anions by medium to heavy textured soils. However, the longevity of this removal is limited because of the small amounts of iron oxides present in most soils. Under anaerobic conditions, precipitation to insoluble FeS and MnS and volatilization of H_2S will result in some $SO_4^=$ loss. For practical purposes, it must be assumed that for both SI and RI, sulfates will not be retained by the soil matrix.

Calcium (Ca^{++}), a prominent cation in wastewater, behaves similarly to sodium and magnesium. Thus Ca^{++} will be involved in cation exchange reactions. While the soil exchange sites tend to accumulate Na^+, the soil solution becomes enriched with respect to Ca^{++}. As mentioned previously, the salt content of the solution will remain fairly constant for both SI and RI operations.

Application of wastewaters to soils is dependent upon the physical filtering phenomena to accomplish the necessary renovation. At the same time wastewater application can destroy this process by plugging the soil pores. Soil clogging can result from excessive amounts of suspended solids. However, this will not be a problem with secondary-treated wastewaters for either SI or RI sites.

4) GROUNDWATER

The quality, quantity and flow regime of groundwater will substantially influence the capacity of a site to renovate wastewater as well as determine the final chemical composition of the leachate from the disposal site.

The depth of the water table affects the suitability of soils to move and renovate wastewaters. Areas with high water tables are not suitable for wastewater disposal because of the reduced infiltration and percolation capacity of the soil. Saturated soils quickly become anaerobic which can reduce not only the favorability of a site for plant growth but also many of the biochemical reactions which are essential for removal of wastewater pollutants.

While the depth of the water table is of primary importance in the renovation of wastewaters, the dilution factor (ratio of groundwater volume to wastewater volume) has a direct relationship to the final water quality from the application site. Concentrations of various constituents in the leachate beneath the disposal site may exceed the requirements for public water supplies, however, dilution by the natural groundwater can produce water of acceptable drinking quality. The USA CRREL research team (1972) believes that dilution by natural groundwater is a strong factor in apparent water quality improvement in many of the RI operations.

Potential impacts to groundwater resources from the additions of large quantities of wastewater can be dramatic. Both qualitative and quantitative changes may occur. Groundwater recharge can prove highly desirable in those areas where increased demands on groundwater resources have resulted in a lowering of the water table and modification of groundwater flow. Concurrently, however, introduction of large quantities of partially renovated wastewater into the groundwater reservoir can lead to local as well as regional problems.

The goal of SI operations should be to approach drinking water quality standards on the site itself. Test wells within the project boundaries should deliver water which would meet EPA requirements for public water supplies. Acceptance of lesser goals seems unwise since current technology is aimed in this direction and could make land disposal obsolete.

The goal of RI operations should be to prevent damage to the groundwater resource. The degree of renovation to be expected from an RI site is quite variable depending on existing ecological conditions. However, the net result of wastewater renovation accomplished at the site (whatever the degree) in conjunction with dilution by the natural groundwater should result in no degradation in water quality on a regional basis. Careful site selection should prevent contamination of nearby wells.

Of the two methods of wastewater disposal, SI is considered to be the most reliable in terms of minimizing groundwater impacts. Failure of an RI operation could impose irrecoverable stresses on the groundwater while failure at an SI operation could be locally contained.

5) VEGETATION AND PRIMARY PRODUCTIVITY

Vegetation is an essential component of an SI operation. For RI, plants are not an absolute requirement, however studies have shown that RI beds covered with a vegetative canopy have and maintain much better infiltration and percolation. Therefore maximum efficiency and longevity are achieved by careful selection and management of the vegetative components of a terrestrial wastewater disposal site. Plants not only remove soluble nutrients, trace metals, etc. but they also protect the soil and complement the microbiological and physiochemical systems in the soil complex.

The basic plant communities associated with existing land disposal sites are forests and agricultural crops. Considerable research has been conducted to determine which plant species in each community are highly adapted to wastewater application in terms of favorable growth responses and degree of nutrient removal. Trees which have shown favorable responses include: white spruce, white, red and scarlet oak, European larch, Japanese larch, white pine, pitch pine, Austrian pine and Norway spruce. Crops which have been successfully used in land disposal operations include: wheat, oats, sweet corn, silage corn, red clover, alfalfa, and reed canary, red top, tall fescue, Bermuda and Sudan grasses.

Of primary concern are the amounts of various nutrients removed annually by croplands and forests. Ideally, the most efficient method is to remove elements from the wastewater via the plant components and then harvest the crop at the end of the growing season. This will effectively extend the life expectancy of the terrestrial system since nutrient recycling is substantially reduced. This method is rather easily applied to agronomic lands, but on forested sites the problem is compounded by the relatively slow growth of trees as well as the natural recycling of minerals and nutrients through the forest litter.

Of all the crops, corn and some of the grasses grown as hay crops seem to have the most favorable renovative capabilities. Both demonstrate significant nutrient uptake and have potential market value following harvest. Corn, however, requires considerably more effort in that annual plowing and planting are required; perrennial grasses require only harvest. Grasses have an additional advantage in that their root systems are fully established at the start of the spraying season and can therefore provide an immediate response. Annual crops on the other hand may allow significant nitrate losses during the early growth period.

Reed canary grass has been used successfully at a variety of SI sites in the United States and seems to be a desirable species. The amount of nutrients removed annually by reed canary grass varies with the amount of wastewater applied, amount of rainfall, length of growing season and the number of cuttings. Results of the Pennsylvania State University studies from 1965-1970 indicate that, at an application rate of 2 inches per week, reed canary grass removed 97.5% of the total added nitrogen but only 35% of the added phosphorus.

It is obvious that phosphorus can not all be removed by agricultural crops; adequate removal is dependent on soil fixation. Of the total phosphorus added over the 6-year period, 35% was removed by the grass crop, 64% was fixed by the soil and 1% leached into the groundwater. Thus, for a 6-year period, a site composed of reed canary grass planted on silt and silt-clay loams removed 97.5% of the added nitrogen and 99% of the added phosphorus.

Trees are not as efficient renovating agents as agronomic crops. Comparison between hardwood trees and silage corn in terms of annual uptake of nitrogen and phosphorus showed that the corn field removed approximately 145% of the applied nitrogen and 143% of the applied phosphorus, whereas the forest plot took up only 39% of the applied nitrogen and 19% of the phosphorus, most of which was returned to the soil by leaf fall. Estimating the magnitude of nutrient removal by trees is difficult because of the problems of measuring the annual storage in the woody tissue and the extent of nutrient recycling in forest litter.

In forest communities the complexities of retention and recycling of the various elements complicate the problem of spray irrigation. It is desirable to remove the forest crop as rapidly as possible to prevent the forest from reaching a state of equilibrium in regard to nutrient cycling. One possibility is to produce rapidly growing species such as cottonwood which could be harvested at 4- to 6-year intervals for pulp production. However, clear-cutting of the forest presents problems; Borman *et al.* (1968) found that this method accelerated the loss of nutrients, including nitrates, into surface waters.

Application of wastewaters to agricultural and forest ecosystems may cause substantial effects to these communities. Not only are increased quantities of nutrients made available but also greater quantities of water. The ability of plants to tolerate these excesses varies with species.

Excessive amounts of nitrogen can be toxic to plants. Toxicity symptoms begin to appear when the nitrogen content surpasses 4 percent of the dry weight of the plant. Excessive levels of phosphorus can also lead to phytotoxicity. In addition the concentration ratios of the elements is important. Certain nutrients, if present in excess, may lead to deficiencies in others. For example, excessive nitrogen often creates deficiencies in potassium, calcium, or magnesium. Phosphates react with heavy metals and can induce metal deficiencies. Zinc deficiency often occurs after heavy additions of phosphorus.

Many of the inorganic constituents of wastewaters are, in trace quantities, essential growth factors for plants. Higher concentrations of the same material can cause phytotoxicity. When a critical level is approached for a particular plant, it may die, not grow properly, or may contain so much of an individual element that the harvest material is not suited for its intended use or it may be toxic to animals which feed on it. It is believed that the composition of wastewaters applied via spray irrigation to agro and forest ecosystems should meet EPA irrigation water requirements in regard to concentrations of boron and heavy metals. This will greatly reduce the likelihood of phytotoxicity as well as sterilization of the soil as a result of high metal concentrations. Both cadmium and chromium exceed the concentration recommended for irrigation water; concentrations of these heavy metals should be reduced. Maintenance of a near-neutral soil pH will reduce the solubility rates of the heavy metals which are added to soils. With time, soil chemical reactions tend to convert adsorbed metal cations to less soluble forms.

Excessive quantities of nutrients and water stimulate vegetative production causing many plants to continue rapid growth late into the season. This may result in mortality since increased vegetative growth reduces the carbohydrate content that is necessary to establish "cold hardiness". Those plants which delay "cold hardiness" are highly susceptible to early frosts.

Two fundamental problems exist in regard to forest ecosystems. Excessively wet soils encourage the development of small, shallow root systems. This condition makes trees highly susceptible to windthrow damage expecially during high winds associated with hurricanes or other storm fronts. In addition, increased growth will be stimulated by the wastewater effluent resulting in morphological changes within the trees. Because of this, the basic wood properties may be modified sufficiently to make trees less suitable for certain forest products. Thus it may be necessary to monitor tree growth and control wastewater application so that the wood is suitable for the desired product.

In an agroecosystem water tolerant crops must be selected; in a forest ecosystem, if natural vegetation is allowed to grow on the disposal site, plant succession will favor water tolerant species. Excessive soil moisture can leach nutrients away from the root zone as well as lead to anaerobic conditions which are not suitable for proper root growth. Actively growing plants can survive short periods of waterlogging but they will succumb if this condition persists for long. Excess water may produce environmental conditions which are highly favorable for insect pests and disease organisms.

Plant uptake of nitrogen and phosphorus as well as other nutrients varies dramatically between species. Studies at Pennsylvania State University (Sopper and Kardos, 1973) were conducted to compare the nutritional differences between agricultural crops and trees grown on spray irrigated and control plots. Crops from irrigated plots contained higher levels of nitrogen and phosphorus than those on control plots. While the differences were significant, they were not large. Foliage analysis of trees and shrubs from the spray irrigated plots were consistently higher in levels of nitrogen, phosphorus, boron, magnesium, copper and sodium and were generally lower in concentrations of potassium, manganese, aluminum and zinc.

Increases in productivity of agroecosystems and forest ecosystems have been noted as a result of spray irrigation (Sopper and Kardos, 1973). During dry years, crops grown on irrigated areas produced greater yields than those on control plots enriched with commercial fertilizer. However, during wet years, crop yields between control and irrigated plots were not significantly different. Coniferous seedlings (8 species) planted in irrigated (on a year round basis) and control plots in an old field showed 88 percent survival after a five year period in the test site vs. 41 percent in the control. In addition, height growth on the irrigated plots was greater in comparison with the control plot. Diameter growth in a mixed hardwood forest 30-50 years of age increased 69 percent in sprayed plots irrigated at a rate of 2 inches per week.

A comparison of mixed stands that had been spray irrigated for 10 years and a variety of natural stands in central Pennsylvania showed no statistical differences in terms of the average number of living and dead trees (mature) per acre (Sopper and Kardos, 1973). There was a drastic reduction of tree seedlings and herbaceous vegetation in the spray irrigated plots. This was probably caused by an increase in canopy cover and a resultant 50 percent reduction in light intensity or perhaps, ice damage as a result of winter spraying.

6) SOIL ORGANISMS

Soil microorganisms and the biochemical reactions in which they participate are beneficial, actually essential, for maintaining the integrity and effectiveness of the soil filter in renovating wastewaters. Only one reaction, nitrification, can be considered somewhat detrimental to the success of wastewater renovation.

One of the most significant functions of soil microbes is the degradation of organic compounds contained in the wastewaters. Indeed, one of the primary advantages of recycling secondary effluent through the soil is that it provides an alternative to expensive tertiary treatments for removing BOD and COD. Physical entrapment and chemical adsorpiton of these compounds in the soil matrix provide sufficient retention time for effective microbial degradation of most of these compounds.

Municipal waste effluents contain a number of organic substances which are potentially very toxic such as phenolic compounds, cholorinated hydrocarbon pesticides, chlorinated biphenyls, ABS, NTA, and petroleum products. The most disruptive environmental impacts would occur if these chemicals moved through or off the soil and into ground and surface waters. Soil microbes are very effective in the degradation of these materials.

It seems likely that the soil filter will effectively eliminate pathogenic bacteria and protozoa reaching the soil from applications of secondary effluent. Survival of viruses is still open to debate because of the paucity of information of this subject. Elimination of pathogens is determined by the effectiveness of both physical and chemical processes which retain the pathogenic organisms long enough for their elimination by the soil microbial population. Rapid movement through coarse textured soils or cracks could certainly provide a means of contaminating groundwater resources.

Of primary concern to land treatment processes is the role of microorganisms in regard to nitrogen budgets--specifically nitrification and denitrification. Nitrification, the conversion of ammonia to nitrate by *Nitrosomonas* spp. and the conversion of nitrite to nitrate by *Nitrobacter* spp. is an important reaction in wastewater management since much of the nitrogen from secondary plants is in the ammonium form. While the end product of nitrification is soluble nitrate, the importance is the time lag which is of benefit to the overall nitrogen removal process as well as rejuvenation of the ammonium retention capacity of the soil. This process is sensitive to changes in soil temperature, moisture and pH. Optimum nitrification occurs at 60°F while the lower limit is near 35°F. Soils with pH values between 5.5 and 7.5 have been found to have rather rapid oxidation of both ammonium and nitrite.

The movement of nitrate through the soil column is impeded primarily by plant uptake and soil microorganisms. Even though some plants, such as grasses, absorb large quantities of nitrogen, the uptake may sometimes be insignificant compared to the total amount being applied. Under such circumstances, microbial immobilization is very important in delaying high concentrations of nitrate from entering the groundwater.

Denitrification is considered to be largely a biological process in which denitrifying bacteria convert nitrates to elemental nitrogen under anaerobic conditions. Anaerobiosis is a process that occurs in specific microsites within the soil profile. Anaerobic and aerobic microsites can occur in very close proximity. Thus the occurrence of denitrification in an aerobic soil profile is quite conceivable. However, in wastewater management one cannot depend on this process for the removal of nitrate from a predominantly aerobic soil profile, because the percentage of microsites where denitrification can occur is small. If one increases the percentage of anaerobic sites to the extent that the soil profile becomes predominantly anaerobic, soil clogging, reduced infiltration and permeability, as well as plant mortality will occur. Optimum temperatures for denitrification are 60° to 65°F and at 35°F this process is practically non-existent.

Denitrification is probably not a significant means of nitrogen removal from spray irrigation sites. However, it can be the dominant means of nitrogen removal from a rapid infiltration system. Bouwer (1970) found that, at the Flushing Meadows RI Site, approximately 70% nitrogen removal was obtained by denitrification processes. He concluded that the quantities of nitrogen introduced to the basin were too high for removal by plant uptake, soil exchange and microbial uptake. He did find a greater reduction of nitrogen in the grass covered plots, however.

There are many additional microbial activities that are beneficial or absolutely essential for successful wastewater renovation. For example, soil microbes increase the effectiveness of phosphorus reactions by mineralizing orthophosphates from the more mobile organic and condensed phosphates so that fixation reactions can occur. Detailed analysis of these activities, however, is beyond the scope of this report.

In general all forms of heterotrophic and autotrophic soil microbes are expected to show an increase in terms of numbers and activity with increased available nutritive material. Many factors influence microbial reactions: heavy metals, toxic organic and inorganic compounds, etc. However, if the soil environment is maintained to provide a relatively high level of aerobic microbial action, normal concentrations of inhibiting substances which occur in "typical" secondary sewage effluent have not been found to induce detrimental effects to the living systems in the soil (Sopper, 1971). Shock loading of inhibitory substances, especially of an inorganic nature, should be avoided.

Addition of wastewater has an impact of lowering soil temperatures, primarily through increasing the rates of evaporation. Decreasing the temperature of the soil decreases the rates of many physiological processes, however the overall efficiency of the soil microbial system will be increased due to the increase in biomass.

7) MAMMALS AND BIRDS

The effects of mammals and birds to terrestrial wastewater management renovation programs are rather minor. The most significant impact would effect the soil component and would occur as a result of high numbers of burrowing mammals. Burrows from moles, maramots, etc. could provide numerous water channels in which the applied sewage effluent would be rapidly channeled through the soil-plant renovating complex. This could conceivably lead to contamination of groundwaters if populations became excessive. Population control measures will be necessary if burrowing becomes a problem.

The effects of wastewater management programs to mammals and birds are both direct and indirect. Direct effects would result from contact with the secondary sewage effluent before it infiltrates into the soil. High concentrations of toxic substances could result in mortality to birds, rodents, etc. through the drinking of wastewater accumulated in small pools or on leaves and other plant surfaces. It is believed that wastewaters applied to land should meet livestock drinking water standards. This would greatly minimize direct effects to populations of birds and mammals.

Indirect effects would result from habitat changes, especially to the soil and plant components. If agricultural crops are incorporated into the renovation site, changes in land use patterns will undoubtedly alter species composition. The end result will be that populations of some species will be greatly reduced or eliminated from the site. These phenomena will not cause substantial disruption to populations within the region, even if a species is eliminated entirely from a wastewater treatment site.

Other species may even benefit from the application of wastewaters and changes in existing land use patterns. As previously indicated, the nutritional composition of plants which are irrigated with sewage effluent are improved. Sopper and Kardos (1973) showed that cottontail rabbits on spray irrigated plots were in much better physiological condition at the end of the winter due primarily to increases in plant biomass and higher nutritional quality of forage. Tests with whitetail deer showed that the animals were not deterred from grazing on spray irrigated plots and grazed them at least as readily as the control plots.

It may be concluded from these studies that the carrying capacity (for some species) on spray irrigated sites exceeds that of untreated sites due mainly to higher levels of available nutrition and improved cover conditions. It is quite feasible that wastewater treatment sites could be managed for game species thus providing considerable recreational benefits.

d) RATIONALE

1) TERRESTRIAL WASTEWATER RENOVATION CONCEPT

It is our belief that terrestrial disposal of the proposed secondary treated wastewaters will not result in adverse ecological impacts and furthermore that the components of terrestrial environments can provide the necessary renovation to meet the water quality goals established earlier.

Successful land renovation programs are dependent upon providing optimum conditions at both SI and RI sites, continuous monitoring of the wastewater composition, and adjustment of application rates in relation to climatologic variables.

Spray irrigation and RI techniques can be equally effective in meeting water quality goals, however, SI is considered the most reliable and would be the least disruptive should temporary overloading or complete system breakdown occur.

Eventually the adsorptive capacity of the soil matrix will become saturated. In addition, the biological responses of the vegetative and soil components may, with time, be severely curtailed as a result of accumulations of toxic substances. Further research is needed to define these long term capacities but in general, they are believed to be quite long (CRREL, 1972).

2) WASTEWATER COMPOSITION AND APPLICATION RATES

The composition of the "proposed" secondary treated wastewater (as depicted in Table 63) meets the requirements for long term spray irrigation except that concentrations of cadmium exceed EPA irrigation water standards by a factor of 10. There are no standards for RI operations; however concentrations of phenols, cadmium, chromium, mercury, manganese and lead in the proposed wastewater exceed EPA requirements for public water supplies. Injections of substantial quantities of wastewaters could degrade the water quality of nearby wells unless sufficiently diluted by the groundwater. Careful site selections will eliminate possible contamination of water supply wells.

Spray irrigation rates of 1.0-2.5 inches per week (26 weeks per year) and rapid infiltration rates of 2.5 and 5 gallons per square foot per day (14 days application - 14 days rest) during the non-freezing periods will not overload the capacities of either SI or RI sites. Discussion of land treatment alternative and agronomic management aspects are discussed in Appendix III - Design and Costs.

3) INTERACTIONS OF ENVIRONMENTAL COMPONENTS

There will be negligible climatological impacts from RI operations; impacts from SI will be local in nature and should pose no major disruptive ecological changes.

New England has a very severe winter climate; neither SI nor RI operations should be undertaken during periods of freezing temperatures (air or soil) which could occur at any time from the beginning of October through the beginning of May. During such times, the renovative capacity of the site is reduced and the likelihood of runoff is increased. In the warmer months, wastewater application should be avoided during periods of intense precipitation. Spray irrigation should not be undertaken during periods of strong winds.

Physiography primarily affects infiltration and permeability rates of soils. On gentle to moderate slopes no changes in soil drainage will occur; wastewaters should not be applied to very steep slopes because of the increased likelihood of surface runoff.

New England topography is quite variable, ranging from nearly level flood plain areas, to very steeply sloping areas of glacial deposits. Much of the existing land within the watershed is suitable for spray irrigation. Both grassland and forest ecosystems can successfully prevent soil erosion even on slopes in excess of a 20 percent gradient. Even steeper areas, if adequately vegetated, can be used for SI with proper application rate adjustments. Because of the substantial quantity of water applied to RI sites, level to nearly level sites should be selected.

A stable aerobic soil profile is an indispensible component of the renovation site. Suitability of the major soils in the study area for wastewater renovation are presented in Table 65.

Medium and heavy textured soils, suitable for SI, should remove most of the organics (oxygen demanding compounds), ammonium, phosphate and heavy metals from the wastewater. Maintaining a near-neutral pH will prevent the metals from leaching. Light textured soils, suitable for RI, should remove most of the organic material. However, much of the ammonium, phosphate and heavy metals will accompany the flow of the leachate.

TABLE 65. SUITABILITY OF SOILS FOR WASTEWATER RENOVATION (SOIL TYPES NAMED ACCORDING TO THE MOST RECENT U.S. SOIL CONSERVATION SERVICE DESIGNATIONS)

SPRAY IRRIGATION	RAPID INFILTRATION	NOT SUITABLE FOR SPRAY IRRIGATION OR RAPID INFILTRATION
Highly suitable:	Highly suitable:	Au Gres (5)
Charlton	Carver	Hollis (6)
*** Narragansett	Enfield	Muck (5)
Enfield	Gloucester	Limerick (5)
	Hinckley	Ridgebury (5)
Moderately suitable:	Merrimack	Saco (5)
Buxton (2)(3)	Windsor	Saugatuck (8)
Canton (1)		Scarboro (5)
Essex (1)		Scituate (7)
Ninigret (silty subsoil) (2)(4)		Swanton (5)
Paxton (1)(4)		Walpole (5)
Suffreid (8)		Whitman (5)
Sutton (1)(2)(3)		Woodbridge (7)
Whately (8)		

(1) Stoniness
(2) Saturated with water during late fall, early spring, heavy precipitation, flooding, etc.
(3) Seasonally high watertable
(4) Low infiltration rate
(5) Saturated with water for most of year
(6) Soil depth too shallow
(7) Conditions promote overland runoff
(8) Shallow hardpan, high infiltration rate

*** Certain critical details concerning soil characteristics not available.

Disposal of the proposed wastewater at the suggested application rates should result in no adverse impacts to the structure of the soil profile or to the physical-chemical-biological reactions which are essential for renovation.

Groundwater fluctuations effect the physical, chemical and biological activities within a soil profile and therefore its ability to renovate wastewater. The dilution of the applied wastewater by natural groundwater is apparently responsible for the success of many RI operations.

Spray irrigation is considered a very reliable technique and can provide water of acceptable drinking quality within the site boundaries. Rapid infiltration on the other hand provides variable renovation and therefore the potential for adverse impacts to groundwater resources is greater.

Plants are essential components of SI sites and are highly desirable for RI beds. While native field and forest communities can provide a certain degree of renovation, maximum wastewater renovation and site longevity can be achieved at both SI and RI sites with a perennial grass ecosystem. Reed canary grass is an ideal species which can remove approximately 97-98% of the added nitrogen and about 35% of the added phosphorous on a yearly basis. Forest stands for a number of reasons can not provide a stable and long term nutrient removal capacity.

Phytotoxicity problems and soil sterility will be avoided if wastewaters meet EPA irrigation water standards. If wastewater is applied to existing plant communities there will be changes in species composition; although overall vegetative responses will be favorable. Primary productivity increases can be expected on SI sites due to increased availability of water and nutrients. Improvement in the nutritional content of plants grown on SI sites can also be expected.

Soil microbes are very efficient in the breakdown and removal of BOD and COD. In addition, they are effective in the elimination of pathogenic bacteria and protozoa. Nitrifying bacteria are important components of the renovation complex in that they delay nitrogen leaching into the groundwater and rejuvenate the ammonium retention capacity of the soil. Denitrification is not a significant means of nitrogen removal at SI sites; however, this process can remove 70 percent of the applied nitrogen from RI operations.

Normal secondary sewage (wastewater) effluent does not contain concentrations of inhibitory substances which would induce detrimental effects to populations of soil organisms (CRREL, 1972). Actually, wastewater application will produce conditions favorable to the increase in biomass of soil microbes.

Birds and mammals have negligible impacts on wastewater management programs; large numbers of burrowing mammals on SI sites will necessitate control measures.

Application of wastewaters can exert both direct and indirect effects on birds and mammals, although substantial population impacts on a regional basis are unlikely.

4) SLUDGE DISPOSAL

The composition, chemical reactivity and concentrations of sludge ash are largely unknown, and must be determined before specific environmental assessments can be made. Information is needed regarding the chemistry of hazardous substances that are produced, or which remain, from the incineration process and their probable fate via disposal in a landfill operation or a wetland. Current literature illustrates the dearth of information regarding the potential hazards of sludge ash disposal (EPA Task Force, 1972; Weber, 1972).

Because of this paucity of data as well as the heavy concentrations of toxic metals and other materials which remain in the ash, it seems prudent to operate on a conservative basis and thereby avoid potentially long-term disruptive impacts. Massive disposal of sludge ash from primary and secondary wastewater treatment in sanitary landfill operations and/or wetlands is unacceptable. Leaching from landfill sites and incorporation of pollutants into groundwater resources is a definite possibility. In wetland ecosystems, exposure to substantial concentrations of heavy metals, etc., could result in both chronic and acute toxicities to both flora and fauna.

Small quantities of ash, if exposed to simulated or actual landfill conditions, will be useful in determining the degree of hazard presented to the environment (EPA

Task Force, 1972). Results of such studies can be used to formulate future sludge ash disposal methodologies applicable to the Merrimack River Watershed.

Regardless of the techniques which are ultimately adopted, sludge ash disposal will require an expenditure of time, energy and money. The continued search for new disposal sites could prove to be rather costly. Therefore, the feasibility of incorporation of the sludge ash into industrial products such as cement, bricks or into road asphalt should be explored. If viewed in terms of conventional economic theories, such practices may seem unworkable. However, if assessed from the viewpoint of elimination of environmental hazards, as well as providing readily available and long term "disposal sites", incorporation into building materials is worthy of consideration.

Additional discussion of sludge and sludge handling methods are discussed in Appendix III - Design and Costs.

IV. WATER QUALITY MODELING OF DO AND BOD LEVELS IN THE MERRIMACK RIVER MAINSTEM AS AFFECTED BY VARIOUS LEVELS OF WASTEWATER TREATMENT

A. INTRODUCTION

This section is a report on the work done with a water quality simulation model as applied to the Merrimack River.

River systems can be viewed as linear systems to evaluate the effects of various inputs. The results of various runs with the simulation model can be an additional input to the decision-making process.

B. OBJECTIVE

The objective of this modeling effort is to evaluate the stream water quality that would result from the various water quality improvement alternatives proposed. Through evaluation of alternatives, we hope to locate possible control points for water quality in the river. In recent years, some people have lost sight of the goal of improving stream water quality and have concentrated on discharge control. Our model is one way to help us relate the costs of effluent control to improvements in stream quality.

C. MODEL METHOD

The water quality simulation model used was developed by Quirk, Lawler and Matusky, consultants to the Commonwealth of Massachusetts. It will be referred to as the QLM model. It is a one-dimensional, steady-state simulation model of a river system. It also has an unsteady state portion which accounts for the diurnal dissolved oxygen variation from photosynthetic activity.

The simulation equation is the mass balance equation. This is the same equation as the familiar Streeter-Phelps equation with terms added to account for other sources and sinks, such as photosynthesis, benthic oxygen demand, storm runoff and uniformly distributed wastewater inputs. The parameters considered are BOD and DO. Other conservative and non-conservative parameters can be introduced. Nitrogenous BOD is included. The river is divided into reaches and computation is done beginning with the upstream end and works toward the mouth of the river. The model is capable of handling tributaries as well as computations on the mainstem. Details about the computation programs are given by Quirk, et al (1).

The model has been run on IBM 360/40, IBM 370/165 and Univac 1108 computers. The computer time required varied with the number of river reaches but generally took only a few seconds of cpu time. It required about 62K bytes of storage on an IBM 370/165.

D. DATA

Data on hydrologic conditions and waste inputs were obtained from various sources. Hydrologic and hydraulic data were obtained from reports by the New England Division, Corps of Engineers and the United States Geological Survey. River coefficients were generally obtained from the report by Camp, Dresser & McKee for the General Accounting Office (2). Waste input data were obtained from various engineering reports by consultants for municipalities and from the files of the National Pollutant Discharge Elimination System Permit Program. Photosynthesis and benthic deposits were obtained from the published results of the 1964-65 survey of the Merrimack (3). Information about the canal systems on the Merrimack were obtained from the files of the New England Electric Company. Water quality information at the stateline was obtained from the New Hampshire Water Pollution Control Division.

E. MODIFICATIONS OF QLM MODEL

Because of the significance of canal systems on the Merrimack, they deserve special attention. Under low flow conditions, they divert and pond the entire flow of the Merrimack. Under these conditions, the canals actually become the river. The QLM model was modified to treat canals as tributaries with water quality conditions at the diversion points as initial conditions for the canals. The model now makes computations for the canal reaches also.

The data available (3) on photosynthesis and benthic deposits were not in a form compatible with the QLM model. The QLM model was set up to expect entry of photosynthesis and algal respiration as separate parameters ($g/m^2/day$). To achieve compatibility, net photosynthesis oxygen production and benthic oxygen demand were input through the algal respiration term in the model.

F. RESULTS

The QLM model as modified was run for the Merrimack River from the New Hampshire-Massachusetts stateline to river mile 22.1 (near Haverhill, Massachusetts) where tidal effects begin.

Tributaries were treated as point sources. The Commonwealth of Massachusetts performed river surveys on some of the tributaries in 1973. When the data from those surveys is available, the tributary option of the model can be utilized to better account for the effects of the tributaries.

G. CALIBRATION

The first step taken with the QLM model was to set up the model to replicate the results obtained in the water quality survey of 1964-65. Without a more recent water quality survey, we used those results as existing conditions.

Hydrologic conditions for the date of the river survey were used (3). This should be distinguished from the seven-day ten-year low flows used for the prediction runs.

Average conditions at the stateline were used as initial water quality conditions (Table 66). These averages were based on the New Hampshire Water Supply and Pollution Control Commission 1970-71 sampling. This meant a BOD of 3.5 mg/l and a DO content of 4.5 mg/l. An ammonia concentration of 3.0 mg/l was also assumed.

Deoxygenation and reaeration constants found in the river survey were used.

Where possible, waste load estimates taken from previous engineering reports and permit applications were used. Industries located on Stony Brook in Chelmsford were assumed to constitute the entire flow from Stony Brook during low flow conditions. Wastes discharged into the canals were adjusted to give agreement with survey results. It was necessary to use immediate oxygen demands to account for oxygen depletion in the canals. As far as we can determine, there has been no analysis of the strength of municipal wastewaters which are discharged into the river at numerous outfalls along urban areas. Therefore, we inputed municipal wastewater as a uniformly distributed discharge along the river banks at Lowell and Lawrence.

Since there is no existing wastewater treatment at Lowell and Lawrence, these wastes were inputed to the model as discharges without treatment (Table 67). Characteristics assumed for the untreated municipal wastewater effluent are comparable to anticipated quality of primary treated domestic wastewater. It should be noted these assumed concentrations are conservatively less than the concentrations used for the design of conventional treatment facilities which are discussed in Appendix III - "Design and Costs."

TABLE 66

ASSUMED INSTREAM WASTE QUALITY AT MASSACHUSETTS-NEW HAMPSHIRE STATELINE RESULTING FROM UPSTREAM DISCHARGE OF PARTIAL AND COMPLETELY NITRIFIED WASTEWATER EFFLUENTS

Parameter (mg/l)	Existing Conditions		Partial	Complete
	No treatment	Secondary treatment	Nitrification at STP	Nitrification at STP
BOD	3.5	1.0	1.0	1.0
DO	4.5	6.5	6.5	6.5
NH_4-N	3.0	0.1	-	-

TABLE 67

ASSUMED QUALITY OF WASTEWATER EFFLUENT DISCHARGED

Parameter (mg/l)	Diluted Untreated Wastes	Secondary Treated Effluent	Partial Nitrification at STP's	Complete Nitrification at STP's
BOD	120	30	30	20
DO	1.0	2	2	2
K_1	0.11	0.11		
Organic-N	14	4	0	0
NH_4-N	11	21	10	1.0
NO_3-N	1.0	1.0	15	26
NO_2-N	0.1	0.0	1.0	0.1

Nitrogenous oxygen demands were assumed to have a lag of 60 hours.

Stormwater was not considered.

Run 1 - Calibration

Figure 29, profile A shows the DO sag curve in the river under "existing" conditions or without treatment. It shows that dissolved oxygen was generally about 4 mg/l until the Lowell canals. After that, it rapidly deteriorated to between 2 and 3 mg/l. It remained at that low level for the rest of the river considered by the stream model.

Figure 30, profile A shows BOD without treatment. BOD was at approximately the upstream level until Chelmsford where the industries discharged their concentrated wastes through Stony Brook. Two large peaks occurred after municipal wastes were discharged at Lowell and Lawrence.

Run 2

The next set of conditions considered was essentially that of the State-EPA Implementation Program.

In this case, interceptor sewers were constructed for Lowell and Lawrence and the wastewater received secondary treatment before discharge. The quality parameters of the effluent discharged after secondary treatment, and which were used in this model, are given in Table 67. Assumed effluent quality was based upon reported effluent characteristics for other secondary treatment facilities operating in Massachusetts (4).

Industries were assumed to remove 90 per cent of their BOD before discharge. All immediate oxygen demands were removed.

Water quality conditions assumed at the stateline are shown in Table 66. However, this quality presumes that uniform secondary treatment is implemented in New Hampshire (see Background Appendix I). The hydrologic condition used was the seven-day ten-year low flow. For the tributaries where no gaging record was available, an estimated flow of 0.01 cfs/mi^2 was used.

We have assumed little, if any, nitrification in secondary treatment plants. We have based our assumption on the fact that few

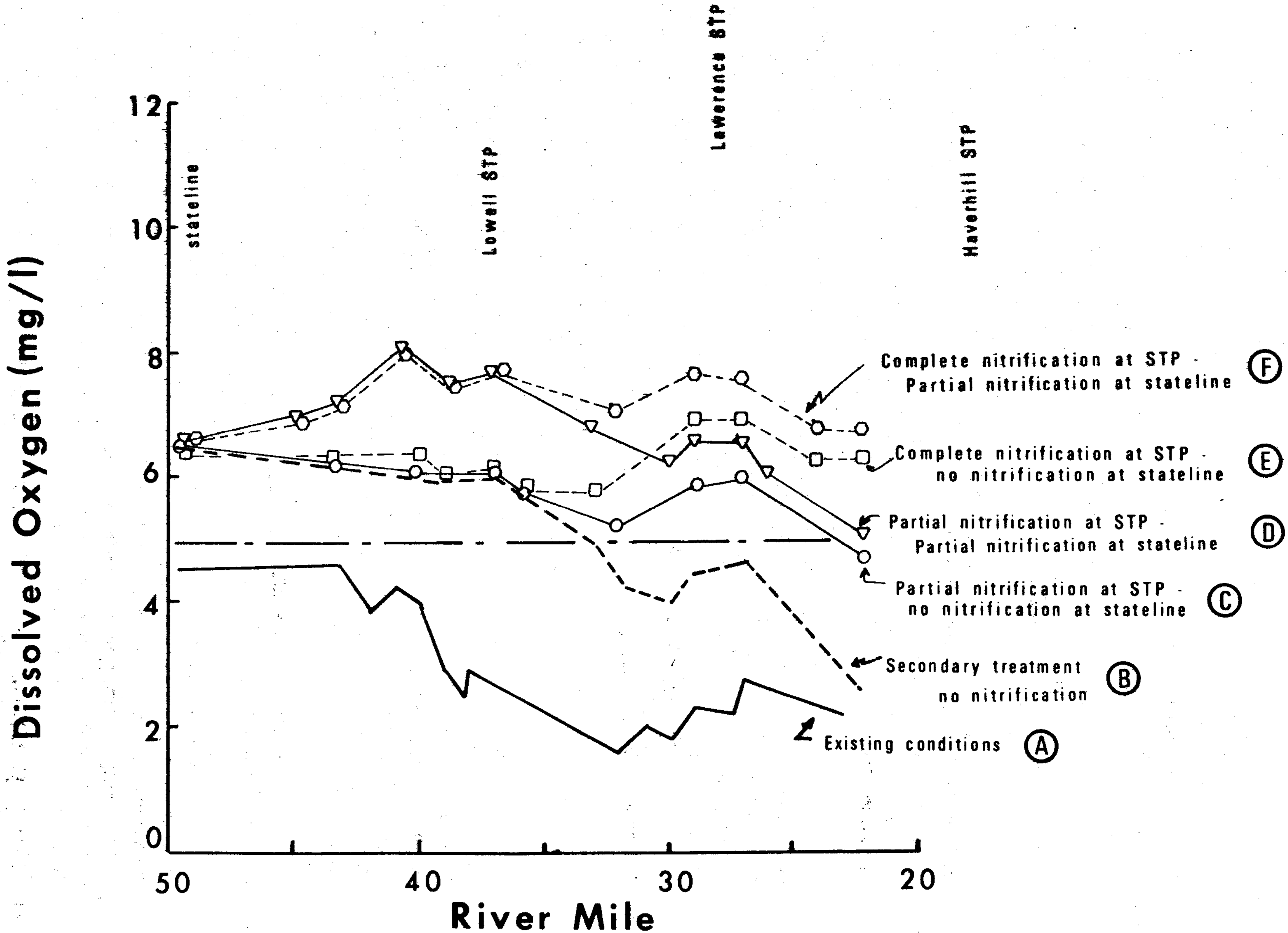

Figure 29 Simulated Effects of Wastewater Treatment on Dissolved Oxygen Levels in Merrimack River Mainstem-Massachusetts

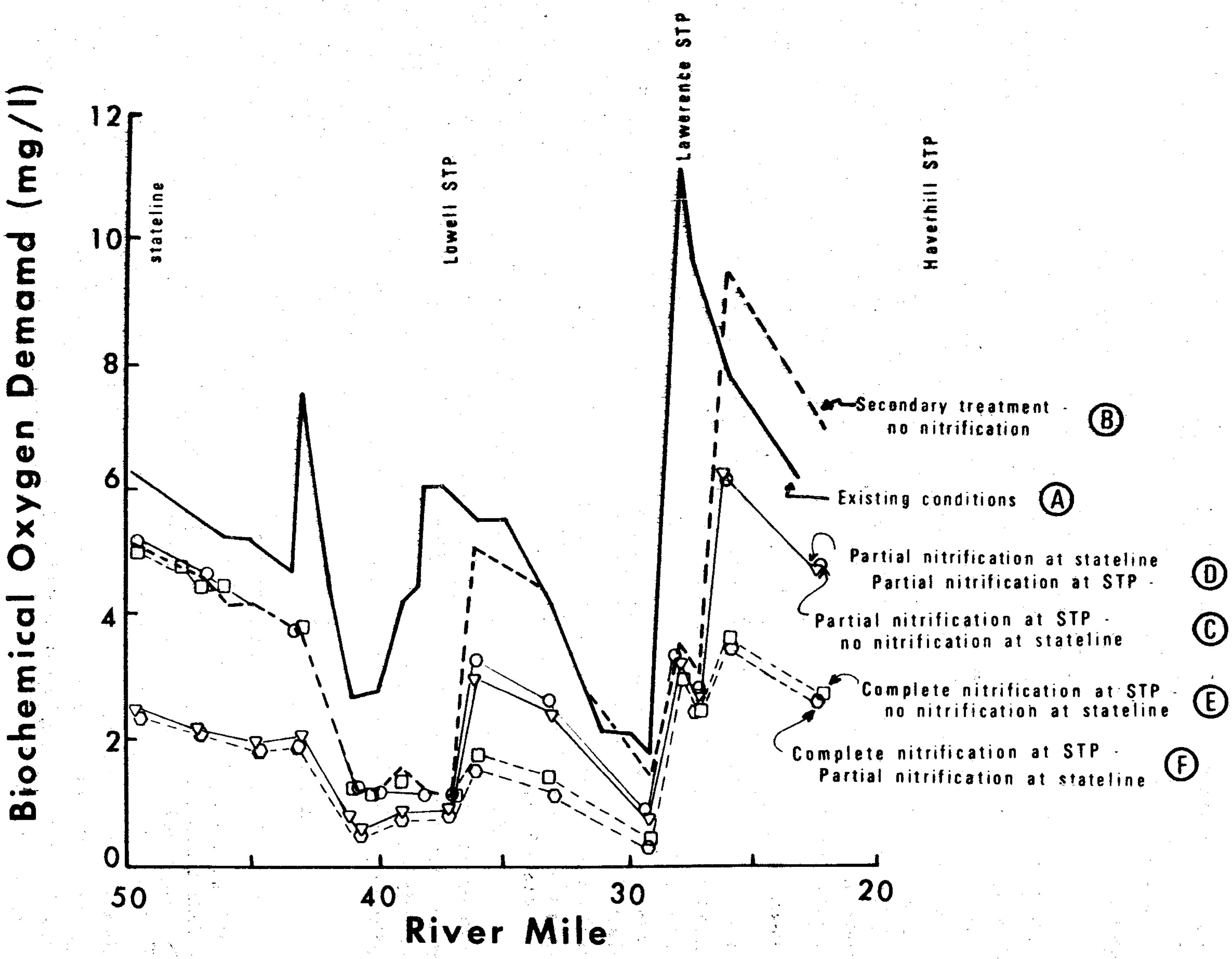

Figure 30 Simulated Effects of Wastewater Treatment on Biochemical Oxygen Demand in Merrimack River Mainstem-Massachusetts

plants can achieve any significant amount of nitrification in conventional biological waste treatment systems in our climatic region. If the secondary treatment plants utilize physical-chemical treatment, there will be no nitrification. Nitrification can be achieved in two or three-stage biological treatment systems, but that alternative is considered in subsequent runs.

Figure 29, profile B shows DO in the river if secondary treatment is implemented. DO starts out at 6-7 mg/l. Some oxygen depletion occurs at the canals but the real depletion occurs after the proposed Lowell and Lawrence wastewater treatment plants. Most of the oxygen depletion occurs as a result of the nitrogenous oxygen demand (lag time of one hour was assumed). Note that the diffuse distribution of wastewater before the installation of interceptor sewers is now modified to form concentrated sources and cause severe oxygen depletion at the proposed outfalls.

Figure 30, profile B shows BOD in the river if secondary treatment is implemented. The figure shows five-day BOD and includes nitrogenous BOD when converted after the lag time. It has been assumed that upstream water pollution control measures have been implemented and at the stateline, the BOD is 1.0 mg/l and ammonia is 0.1 mg/l. One can see the tremendous peaks of BOD immediately following the discharge of secondary effluent at the proposed treatment plants at Lowell and Lawrence.

These profiles show that significant degradation of stream water quality can result with dissolved oxygen dropping below 3.0 mg/l near the tidal portion of the river. Moreover, the model does not consider possible eutrophication problems associated with the discharge of nutrients, which could further depress dissolved oxygen levels.

Run 3

As was demonstrated in the previous run, the conversion of ammonia to nitrite and nitrate consumes large amounts of dissolved oxygen. The removal or conversion of ammonia to nitrate prior to effluent discharge will alleviate part of the DO problem. In many biological wastewater treatment plants, it is possible to achieve some degree of ammonia conversion in either single-stage or multiple-stage plants. This run investigates the effect of partially nitrified effluent discharged from what is now known as best practical wastewater treatment facilities.

The inputs for this run were identical to Run 2 (secondary treatment) except the effluents from the Lowell wastewater treatment plant and the Greater Lawrence Sanitary District (GLSD) wastewater treatment facility were assumed to be partially nitrified. Nitrogen levels assumed in the effluent are shown in Table 67.

Profile C, figures 29 and 30 show the DO and BOD profiles resulting from partial nitrification with only secondary treatment upstream of the stateline. It can be seen that the water quality from the stateline to the Lowell wastewater treatment plant is the same as for secondary treatment. From this point to the GLSD, there is less oxygen depletion and lower BOD to the stream with partial nitrification at Lowell. With partial nitrification, the minimum DO in this stretch is about 5 mg/l while that for secondary treatment was about 4 mg/l.

The addition of nitrogenous BOD at Lowell caused a jump to 5 mg/l with secondary treatment but only 3 mg/l with partial nitrification. Thus, the marginal water quality improvement in this stretch from partial nitrification of secondary effluent is about 1 mg/l of DO and 2 mg/l of BOD.

From the GLSD to the tidal limits, partial nitrification caused the DO to drop from 6.0 mg/l to 4.7 mg/l and BOD to rise from 2.7 mg/l to 6.3 mg/l at the outfall. When only secondary treatment is provided, the DO sag was from 4.7 mg/l to 2.6 mg/l and BOD rose from 3.1 mg/l to 9.5 mg/l. The marginal water quality improvement in this stretch from partial nitrification of secondary effluent at the wastewater treatment plants is 2 mg/l of oxygen deficit at the trough and 3 mg/l less of BOD at the outfall.

Secondly, the effect of partial nitrification above the stateline was modeled in this run. The ammonia level at the stateline was assumed at 0.6 mg/l (Profile C, figures 29 and 30).

From the stateline to Lowell, partial nitrification raises the DO from 6 mg/l to 8 mg/l and reduces BOD from 5 mg/l at the stateline to 2 mg/l. Improved water quality at the stateline would permit discharge of partial nitrified effluents at Lowell without reducing downstream DO levels below 5 mg/l. From Lowell to Lawrence, DO only drops to 6 mg/l while BOD increases below the Lowell outfall to about 3 mg/l. In this stretch, the marginal water quality benefits gained from partial nitrification above the stateline and the Lowell treatment plants are an increase of 2.5 mg/l DO and decrease of 2.5 mg/l BOD, compared to DO and BOD levels expected without partial nitrification in the New Hampshire portion of the river.

From Lawrence to tidal limits, the effect of partial nitrification at the stateline becomes hardly discernable from water quality resulting from no nitrification at the stateline. Dissolved oxygen depletion and BOD increase from the wastes discharged at Lawrence are almost identical in both cases.

Run 4

Many forms of advanced waste treatment proposed include the complete removal of nitrogen in effluents (See Appendix III - Design and Costs). This run examines the effects of complete nitrification on water quality. The additional step of denitrification has no direct impact on DO and BOD in the stream so the results of this run also apply to the advanced treatment (zero discharge) processes proposed by the wastewater management study.

Although complete nitrification of effluent would have little direct effect upon the DO and BOD levels in the stream, it must be pointed out that conversion of organic and ammonia nitrogen to the nitrate form does not remove the possibilities of increased algal growth. Rather nitrification will essentially make the nitrogen discharge more readily available for algal uptake and increased algal growth. Therefore, discharging highly nitrified effluents greatly increases the probability that anticipated improvement of dissolved oxygen and biochemical oxygen demand levels will be offset by regeneration of organic matter through natural processes. Anticipated quality of completely nitrified effluent is shown in Table 67.

First, we considered the effect of complete nitrification at the two wastewater treatment plants, but no nitrification at all upstream (Profile E, figures 29 and 30).

The inputs for this simulation were the same as for secondary treatment except that the waste loads in terms of nitrogenous and carbonaceous BODs were changed. The results show that from the stateline to Lowell, the water quality is the same as Run 2 (secondary treatment). From Lowell to Lawrence, there are no significant changes in either the DO sag or in additional BOD. DO remains relatively constant and BOD shows an increase of 0.7 mg/l below the Lowell treatment plant. Compared to partial nitrification at the treatment facility, the marginal water quality benefits are about 0.4 mg/l DO and 1.5 mg/l BOD. When compared to secondary treatment, the marginal water quality improvement is 2.0 mg/l DO and 3.3 mg/l of BOD.

From Lawrence to the tidal limits, there is a small DO sag of 0.5 mg/l and BOD increases to 3.0 mg/l after the GLSD plant. Compared to the partial nitrification scheme, there is a marginal DO improvement of about 1.7 mg/l and a marginal BOD deterioration of 0.3 mg/l. When compared to secondary treatment, complete nitrification improves DO by 3.8 mg/l and the marginal BOD deterioration is 0.6 mg/l less.

Next, we examined the effect of partial nitrification at the stateline (0.6 mg/l $NH_3)^{-N}$ and complete nitrification at the Lowell and Lawrence wastewater treatment plants (Profile F, figures 29 and 30). In this case, from the stateline to Lowell, the water quality is the same as other runs in which effluents discharged were first partially nitrified. From Lowell to Lawrence, the water quality is only slightly improved from that of no nitrification at stateline and complete nitrification at the Lowell plant; DO reaches a minimum of 7.1 mg/l, BOD increases to 1.6 mg/l at the outfall. This is significantly better than secondary treatment which gave a minimum DO of 4.0 mg/l and a BOD of 2 mg/l for partial or no nitrification upstream and complete nitrification at the plant.

Discussion

The simulation runs presented above show the incremental water quality improvements that can be obtained with different levels of wastewater treatment. These benefits should be evaluated against the costs of such alternatives.

The Merrimack River can be divided into three segments. The segment from the stateline to Lowell is influenced most heavily by water quality at the stateline. The industries at Stony Brook (Chelmsford) are of some influence but their influence is minimal once best practicable control technology is employed. Thereafter, the water quality depends solely on upstream practices.

The second segment is between Lowell and Lawrence. This segment is influenced by the Lowell canals and Lowell's municipal wastewaters and to a small degree water quality at the stateline. When the interceptor sewers are in place and the industries achieve best practicable control technologies, the sole control becomes the wastewater treatment plant at Lowell.

The last segment runs from Lawrence to the tidal limits. The inputs that influence the water quality in this segment are the Lawrence canals and municipal wastes. For this segment, the sole control after the construction of wastewater treatment plants becomes the GLSD wastewater treatment plant.

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V. IMPACTS OF WASTEWATER MANAGEMENT ALTERNATIVES

A. INTRODUCTION

In order to assess the environmental impact of secondary and advanced wastewater treatment alternatives on aquatic communities in the Merrimack River Basin, a number of preliminary assumptions are as follows:

1) The river discharge will be the 7 day - 10 year low flow value.

2) The temperature of the river will be the mean late summer (July-August) value.

3) Base line water quality of the River system at the Massachusetts-New Hampshire state line will not be substantially altered [population increase of 1.3 per cent by 2020, pers. comm. New Hampshire Planning Commission, 1974] when the statewide (Massachusetts) secondary implementation plan goes into operation. The base line water quality will be altered by the institution of AWT in New Hampshire; a new base line based on AWT will be developed for the evaluation of Massachusetts AWT alternatives.

4) Effluent discharge flows and constituent concentrations for the waste treatment alternatives are those estimated by consulting engineers and the U.S. Army Corps of Engineers. Inherent in this assumption is strict adherence to the EPA's NPDES (National Pollutant Discharge Elimination System).

5) The aquatic system under consideration will be in equilibrium so that cycling of materials through the biota and sediments will not produce a net gain or loss.

When treated waste is discharged into the receiving stream it maintains itself as a well defined plume until vertical and lateral turbulence mix it completely with the receiving water. The initial environmental impact of such a discharge would result from direct biological community contact with the undiluted effluent constituents, while the minimum impact would result from community contact with the completely diluted effluent. The diluted concentration of any constituent after complete mixing is given in the formula below:

$$C_D{}^{1} = \frac{(C_R Q_R) + (C_E Q_E)}{Q_R + Q_E}$$

where

C_D = hypothetical average concentration of constituents in receiving water below effluent (mg/l)

C_R = concentration of constituent in receiving water above effluent (mg/l)

C_E = concentration of constituent in the effluent (mg/l)

Q_R = discharge of receiving stream (l/sec)

Q_E = discharge of effluent (l/sec)

To determine the concentrations of fully mixed effluents below subsequent outfalls, all upstream concentration values are taken into consideration in the following formula:

$$C_{D_n} = \frac{\sum_{j=1}^{n} (C_R Q_R) + (C_{E_1} Q_{E_1}) + (C_{E_2} Q_{E_2}) + \ldots + (C_{E_n} Q_{E_n})}{\sum_{j=1}^{n} Q_R + Q_{E_1} + Q_{E_2} + \ldots + Q_{E_n}}$$

This simplistic model was adapted to estimate the concentration of effluent constituents after each effluent mixing. Concentrations resulting from each addition were compared to Environmental Protection Agency (1973) proposed criteria, Commonwealth of Massachusetts (1968) criteria for class B waters, and data from scientific literature, to assess the environmental impact of the

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[1]Adopted from Kitrell (1969). A practical guide to water quality studies of streams. U.S.D.I., FWPCA, CWR-5.

various waste treatment alternatives. The water quality criteria developed by the Environmental Protection Agency was heavily relied upon in making evaluations. When such criteria were lacking the most recent scientific literature was consulted (e.g. nutrients).

Obviously, this model works best for conservative materials, but limitations of data and time have eliminated consideration of more elaborate treatment. The simple model presented above was applied to all effluent constituents, both conservative and non-conservative. Since chemical, biological, and physical interactions were not considered, the "concentrations" derived from the river-effluent model were considered only as a general index of waste loading for poorly conserved parameters (e.g. nitrogen compounds). Concentrations having the most evaluative validity are those found in close proximity to the outfall (i.e. outfall concentrations). It should also be mentioned that resynthesis of organic material from available nutrients will occur primarily in impounded areas of the river. Since this model is adapted only to direct flow through or static situations, it could not be applied to estuarine discharges. At present, knowledge of circulation and diffusion patterns existing in the Merrimack River estuary is not of sufficient detail to validate even a semi-quantitative approach to wastewater dilution phenomena.

The wastewater management alternatives were considered as areal and conceptual unities [e.g. Alternate 1 (Water Oriented Decentralized) for the Northern Middlesex Area and Alternate 1 (Water Oriented Decentralized) for the Merrimack Valley Planning Commission Area were considered together as a Water Oriented Decentralized Alternative for the entire Massachusetts Section of the Merrimack River Basin]. Detailed evaluative data used to arrive at these conclusions are presented in Volume 2.

In assessing the environmental impact of secondary and advanced wastewater management proposals to terrestrial ecosystems, the following assumptions are made:

1) For both SI and RI, ideal environmental conditions (topography, soils and vegetation) prevail at each site.

2) Wastewater composition meets EPA irrigation water standards for use on all soils for indefinite periods of time.

3) Wastewater application is restricted during periods of adverse weather (heavy precipitation, freezing temperatures, etc.)

4) Application rates and schedules are those estimated by the U.S. Army Corps of Engineers.

The tabular representation of positive, neutral and negative impacts to both aquatic and terrestrial ecosystems was adapted to interface with the format used by other consultants. Environmental impacts to the various components of the biota of aquatic ecosystems are presented below:

PLANKTON:	+ Reduction of Bloom Potential, and Taste and Odor Problems
	O No Reduction
	- Increased Potential for Blooms and Taste and Odor Problems
AQUATIC MACROPHYTES:	+ Reduced Deleterious Production
	O No Reduction
	- Increased Deleterious Production
INVERTEBRATES:	+ Increased Diversity
	O No Change
	- Decreased Diversity
FISH:	+ Increased Diversity, Elimination of Food Fish Tainting, and Build-up of Toxic Materials
	O No Change
	- Decreased Diversity, Increased Food Fish Tainting, and Build-up of Toxic Materials.

The following interpretations of terrestrial impact assessment symbols apply to ecosystem components presented for water oriented alternatives, including the state implementation plan:

Soil	0	Impact is limited to the area immediately surrounding the disposal/facility site.
	-	Construction of the treatment plant would permanently alter local soil character; deposition of sludge would contaminate soil with toxic residuals (e.g. heavy metals)

Vegetation	0	Impact is limited to the area immediately surrounding the disposal/facility site.
	-	Construction of the treatment plant would alter the character of natural vegetation; deposition of sludges would injure plants that are sensitive to high concentrations of certain residuals (e.g. phosphorus and heavy metals).
Wildlife	0	Impact is limited to the area immediately surrounding the disposal/facility site.
	-	Habitat would be destroyed by facility construction; concentration of toxic residuals in sludge may cause mortality to birds, rodents, etc. which drink the runoff or consume the vegetation at the disposal site.
Groundwater	0	Impact is negligible.
	0[1]	Leachate from disposal site may eventually disseminate substance which are toxic or high in biochemical oxygen demand.
	-	Quality of leachate would be poorest in the proximity of the disposal site.

B. LOCAL EFFECTS OF PROPOSED WASTEWATER PLANS

The localized impact of both secondary and AWT effluent water entering natural surface waters will, of course, be much less than that of untreated or primarily treated effluent. However, they will have an impact on the biota. These impacts are discussed below relative to the predicted general characteristics of the receiving stream after the institution of the level of treatment being discussed.

1. Secondarily Treated Effluent (see Figure 31, Table 68).

   a) Physical -- There is likely to be a local increase in turbidity. The overall impact on all biological communities of this environmental alteration is probably neutral.

   b) Chemical

      1) Primary Productivity -- Unless inhibited by phytotoxic materials (Hg, Mn, and Ni), an increase in periphyton and aquatic macrophyte production is forseen in the immediate vicinity of the outfall due to locally increased nutrient availibility. It is likely that this zone of increased primary productivity will also biomagnify some heavy metals present in the effluent discharge.

      2) Invertebrates -- Invertebrate organisms (zooplankton, macro-, and micro-benthos) will be subject to a variety of materials at toxic concentrations (e.g. NH_3, residual Cl_2, and Metals). It is expected that more sensitive organisms will not be able to establish viable populations in the immediate vicinity of the outfall, and that those organisms that do survive will have limited reproductive success due to the action of toxic materials. It is also expected that invertebrate organisms in the immediate vicinity of the outfall will biomagnify some heavy metals present in the wastewater effluent.

      3) Fish -- Fish species sensitive to ammonia, chlorine, and other effluent constituents (typically game and forage fish) will probably avoid the immediate vicinity of the discharge, while rough fish may locally increase in relative abundance. Those fish which remain in the immediate vicinity of the discharge are likely to suffer chronic sublethal effects from toxic materials present in the discharge (e.g. tainting of edible species, reduced reproductive success, reduced viability, etc.).

c) Magnitude of Localized Effects

The magnitude of localized impacts will be dependent upon the volume of wastewater impact relative to river discharge. As indicated by Table 68, the greatest localized impacts would be expected to occur in the Merrimack River at the Lawrence, Massachusetts discharge, while the smallest will occur at the Merrimack, Massachusetts discharge.

TABLE 68
STATE IMPLEMENTATION PLAN. PERCENT OUTFALL CONTRIBUTION TO 7 DAY - 10 YEAR LOW FLOW.

Outfall Location	Discharge (MGD)	Receiving Stream	% 7 Day-10 Year Low Flow
Billerica	1.60	Concord River	8.83
Lowell	31.60	Merrimack River	5.53
Lawrence	52.00	Merrimack River	8.80
Haverhill	18.11	Merrimack River	3.60
Merrimack	0.53	Merrimack River	0.09
Amesbury	1.90	Merrimack River	0.32

2. Advanced Wastewater Treatment Effluent (See Figures 32-36, Table 69).

a) Physical -- There is likely to be a local increase in turbidity. The overall impact on all biological communities of this environmental alteration is probably neutral.

b) Chemical

1) <u>Primary Productivity</u> -- Localized increases in periphyton and aquatic macrophyte production due to nutrient enrichment. According to effluent specifications for AWT, no phytotoxic materials are expected in the effluent.

2) <u>Invertebrates</u> -- Invertebrate organisms (zooplankton, macro-, and micro-benthos) may be locally subjected to toxic action from ammonia, residual chlorine, and

chloramines. This toxic action may prevent more sensitive organisms from establishing a viable population in the immediate vicinity of the outfall, and possibly reduce the reproductive success of less sensitive forms.

3) Fish -- Fish sensitive to ammonia, residual chlorine, and chloramines will probably avoid the immediate vicinity of the discharge, consequently, less sensitive rough species may locally increase in relative abundance. Those fish which remain in the immediate vicinity of the effluent may possibly suffer from decreased reproductive success and decreased viability.

c) Magnitude of Local Effects

The magnitude of local effects will be dependent upon the volume of wastewater inflow relative to river discharge (see Table 69).

TABLE 69
ADVANCED WASTEWATER TREATMENT ALTERNATIVES
PERCENT OUTFALL CONTRIBUTION TO 7 DAY-10 YEAR LOW FLOW.

ALTERNATIVE 1

Water Oriented Decentralized

Outfall Location	Discharge (MGD)		Receiving Stream	% 7 Day-10 Year Low Flow	
	1990	2020		1990	2020
Billerica	7.25	12.43	Concord River	40.05	68.67
Amesbury	1.86	3.31	Powwow River	58.62	104.32
North Chelmsford	0.81	6.71	Merrimack River	00.14	1.17
Lowell	24.12	33.10	Merrimack River	4.08	5.60
Lawrence	43.61	60.12	Merrimack River	7.38	10.18
Haverhill	13.19	19.50	Merrimack River	2.23	3.30
Newburyport	3.05	4.45	Estuary or Ocean	0.52	0.75
Salisbury	1.67	2.13	Estuary or Ocean	0.28	0.36

ALTERNATE 2

Water Oriented Partially Decentralized

Outfall Location	Discharge (MGD) 1990	Discharge (MGD) 2020	Receiving Stream	% 7 Day-10 Year Low Flow 1990	% 7 Day-10 Year Low Flow 2020
Lowell	32.18	52.24	Merrimack River	5.44	8.84
Lawrence	43.61	59.25	Merrimack River	7.38	10.03
Haverhill	13.19	19.50	Merrimack River	2.23	3.30
Amesbury	1.55	2.36	Merrimack River	0.26	0.40

ALTERNATE 3

Water Oriented Centralized

Outfall Location	Discharge (MGD) 1990	Discharge (MGD) 2020	Receiving Stream	% 7 Day-10 Year Low Flow 1990	% 7 Day-10 Year Low Flow 2020
Concord	32.18	52.24	Concord River	177.74	288.62
Lawrence	56.80	80.21	Merrimack River	9.61	13.57
Newburyport	6.58	10.32	Estuary	1.11	1.75

ALTERNATE 4

Water Oriented Regional

Outfall Location	Discharge (MGD) 1990	Discharge (MGD) 2020	Receiving Stream	% 7 Day-10 Year Low Flow 1990	% 7 Day-10 Year Low Flow 2020
Lawrence	88.98	132.45	Merrimack River	15.06	22.41
Newburyport	6.58	10.32	Estuary	1.11	1.75

ALTERNATES 5 AND 6

Land Alternatives

Outfall Location	Discharge (MGD) 1990	Discharge (MGD) 2020	Receiving Stream	% 7 Day-10 Year Low Flow 1990	% 7 Day-10 Year Low Flow 2020
Lawrence	43.61	60.12	Merrimack River	7.38	10.17
Newburyport*	3.05	4.45	Estuary	0.52	0.75

* Secondary Effluent

C. GENERAL EFFECTS OF PROPOSED WASTEWATER PLANS

1. State Implementation Plan (Figure 31)

The institution of secondary level treatment for the Massachusetts section of the Merrimack River basin will undoubtedly reduce the immediate biochemical oxygen demand (B.O.D.) and suspended solids loading of the affected receiving streams. However, the real and apparent problems of oxygen demanding material resynthesis from available nutrients by primary producers, and the introduction of trace metals and other toxic materials will not be eliminated by this level of treatment. It is apparent from water quality data that it is already a highly nutrient enriched system. When combined with future increased waste inflows, the existing impoundments, and high levels of phytoplankton primary productivity, there is a potential for nuisance algal problems and resultant dissolved oxygen demands. In the Concord River (a naturally enriched system) the same comments hold true. It is likely that under secondary treatment the establishment of an anadromous fishery is possible, although this would probably result from fortuitious timing of the upstream runs in the Merrimack River by Atlantic salmon and the tolerance of the American shad. In the case of the little studied shad, which will spend more time in the Massachusetts portion of the Merrimack River basin, sub-lethal impacts on the fish population must be considered.

A concern which must be seriously considered by Public Health personnel is the problem of biomagnification of trace metals by finfish in the Merrimack basin and the commercially and recreationally important soft-shell clam in the Merrimack River estuary. There is likely to be some decrease in the organic content of the affected river sediments, however, it is not felt that their content of trace metals and other toxic materials will be substantially altered.

The State Implementation Plan will primarily affect terrestrial ecosystems through sludge or sludge ash disposal via wetland or sanitary landfill operations. Toxicity to wetland ecosystems and eventual leaching of contaminants into groundwaters are likely to occur from such disposal techniques. Therefore, it is believed that application of sludge materials to terrestrial or wetland areas could result in both short and long-term disruptive impacts.

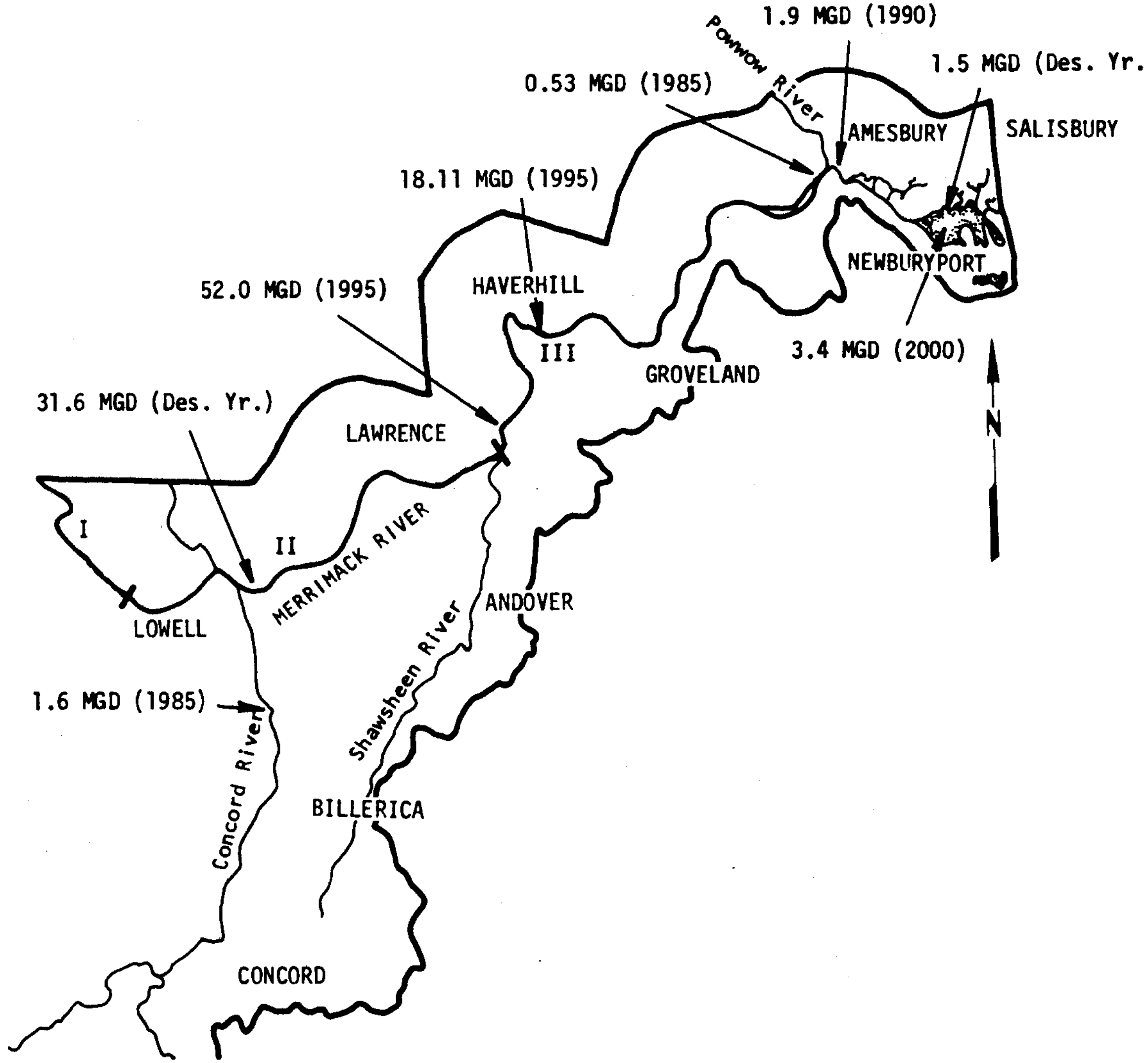

Figure 31. **Wastewater inputs to the aquatic ecosystem - MGD = Million gallons / day** State/EPA Implementation Program

The utilization of land for the purpose of construction of treatment facilities will result in adverse impacts to existing terrestrial ecosystems within the project boundaries. However, when considered on a regional basis, these impacts are negligible.

Potential environmental impacts of the State Implementation Plan to aquatic and terrestrial ecosystems is presented in Table 70.

a) Physical Effects

1) Concord River -- Increased water inputs will tend to stabilize summer low flows in the Concord River below the Billerica outfall. Such a flow stabilization will have a generally positive effect on the river. This flow increase could possibly increase dissolved oxygen and reduce solar heating of the stream during periods of low flow. No significant impact on stream turbidity is expected.

2) Powwow River -- Absence of wastewater effluent in the Powwow River will reduce flows, however, it is not expected to significantly alter the physical environment.

3) Merrimack River, Area I -- No outfalls are to be located in this area so that neutral or slightly positive impacts are expected as a result of reduced turbidity.

4) Merrimack River, Area II -- The location of the Lowell outfall will not substantially alter Merrimack River physical (flow, turbidity, etc.) characteristics in Area II.

5) Merrimack River, Area III -- Same reduction in turbidity levels and consequently increased light penetration is expected.

6) Merrimack River Estuary -- The location of the estuarine outfalls will not substantially alter estuarine physical parameters.

b) Chemical Effects

1) Concord River

aa. Primary Productivity -- Since the Concord River is already a highly enriched stream, no net increase or decrease of production by phytoplankton, periphyton or aquatic macrophytes is expected. These communities would be expected to biomagnify some heavy metals present in the effluent. Some phytotoxic action by mercury is possible.

TABLE 70. POTENTIAL AQUATIC AND TERRESTRIAL IMPACTS OF STATE IMPLEMENTATION PLAN

AQUATIC

	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III	ESTUARY
Plankton	O	+	O	-	-	O
Aquatic Macrophytes	O	+	O	O	O	O
Invertebrates (Fish Food Organisms)	O	+	O	O	O	O
Fish	O	+	O	O	O	O

TERRESTRIAL

	TREATMENT FACILITIES (Local)	TREATMENT FACILITIES (Regional)	TREATMENT SLUDGES (Local)	TREATMENT SLUDGES (Regional)
Soil	-	O	-	O
Vegetation	-	O	-	O
Wildlife	-	O	-	O
Groundwater	O	O	-	O[1]

LOCAL / REGIONAL

[1]Long term effects may be negative

bb. Invertebrates -- No substantial change in the invertebrate community is expected in the affected area of the Concord River. Although biochemical oxygen demand will be reduced, resynthesis of organic materials from available nutrients and their subsequent decay will tend to negate the effect of biochemical oxygen demand removal. Expected cadmium concentrations are likely to reduce the fecundity of microinvertebrates (e.g. *Daphnia* spp.), and be biomagnified by macroinvertebrates. Mercury, although not expected to occur at an acutely toxic level, could exert chronic sublethal effects on the invertebrate community. Other metals are likely to be biomagnified by invertebrates and have synergystic effects. Chronic sublethal effects of these metals on invertebrate organisms are not well studied.

cc. Fish -- The fisheries population existing in the Concord River is expected to be neutrally impacted by the institution of secondary treatment at Billerica, as no substantial change in dissolved oxygen or toxicant levels is expected. Expected phenolic residues could possibly taint edible fish. Cadmium is not expected to occur in concentrations which would be acutely toxic to adult fish, however, it could be toxic to the more sensitive eggs and larvae. Mercury could possibly occur in concentrations which would be toxic to sensitive fish species. It is expected that the fisheries community will biomagnify all heavy metals. The expected mercury concentrations are such that biomagnification of this metal could reduce gamefish utility.

dd. Summary -- No substantial environmental improvements can be forseen after the institution of secondary level treatment for wastewater entering the Concord River at Billerica. This is largely due to projected increased wastewater inputs. It must be pointed out, however, that without at least secondary treatment, increased wastewater flows would likely have a highly negative impact on the Concord River ecosystem.

2) Powwow River -- No secondary wastewater outfalls are located on this river, hence the state implementation plan would have a neutral to somewhat positive impact on the Powwow River ecosystem.

3) Merrimack River, Area I -- No secondary wastewater outfalls are located on this stretch of river, thus a neutral or somewhat positive environmental impact is expected for this area.

4) Merrimack River Area II

aa. Primary Productivity -- Increased wastewater flows without nutrient removal could cause increased primary productivity behind the Essex Dam at Lawrence, Massachusetts. Some phytotoxic action can be expected from metal ions introduced by the effluent water.

bb. Invertebrates -- No substantial change in the invertebrate community is expected in Area II of the Merrimack River. Although biochemical oxygen demand will be reduced, resynthesis of organic materials from available nutrients and their subsequent decay could tend to negate the effect of biochemical oxygen demand removal. Expected cadmium concentrations are likely to reduce the fecundity of microinvertebrates (e.g. *Daphnia* spp.), and be biomagnified by macroinvertebrates. Mercury, although not expected to occur at an acutely toxic level, could exert chronic sublethal effects on the invertebrate community. Other metals are likely to be biomagnified by invertebrates and have synergystic effects. Chronic sublethal effects of these metals on invertebrate organisms are not well studied.

cc. Fish -- The fisheries population existing in Area II of the Merrimack River is expected to be neutrally impacted by the institution of secondary treatment, as no substantial change in dissolved oxygen or toxicant levels is expected.

Expected phenolic residues could possibly taint edible fish. Cadmium is not expected to occur in concentrations which would be acutely toxic to adult fish, however, it could be toxic to the more sensitive eggs and larvae. Mercury could possibly occur in concentrations which would be toxic to sensitive fish species. It is expected that the fisheries community will biomagnify all heavy metals. The expected mercury concentrations are such that biomagnification of this metal could reduce gamefish utility. Below Lawrence the secondary effluent will comprise 23.16% of the 7-day 10 year low flow. Such a concentration of secondary effluent is known to taint fish flesh, and this effect is expected to occur in the Merrimack River below Lawrence.

dd. Summary -- No substantial environmental improvements can be forseen after the institution of secondary level treatment for wastewater entering Area II of the Merrimack River. This is largely due to projected increased wastewater inputs. It must be pointed out, however, that without at least secondary treatment, increased wastewater flows would likely have a highly negative impact on the biota of Area II.

5) Merrimack River, Area III

aa. Primary Productivity -- Increased flows of wastewater without nutrient removal and decreased turbidity could increase primary productivity in the tidally impounded Area III of the Merrimack River, unless phytotoxic materials become concentrated in this impounded section.

bb. Invertebrates -- No substantial change in the invertebrate community is expected in Area III of the Merrimack River. Although biochemical oxygen demand will be reduced, resynthesis of organic materials from available nutrients and their subsequent decay will tend to negate the effect of biochemical oxygen demand removal. Expected cadmium concentrations are likely to reduce the fecundity of microinvertebrates (e.g. Daphnia spp.), and be biomagnified by macroinvertebrates. Mercury, although not expected to occur at an acutely toxic level, could exert chronic sublethal effects on the invertebrate community. Other metals are likely to be biomagnified by invertebrates and have synergistic effects. Chronic sublethal effects of these metals on invertebrate organisms are not well studied.

cc. Fish -- The fisheries population existing in Area III of the Merrimack River is expected to be neutrally impacted by the institution of secondary treatment. Although it is likely that dissolved oxygen conditions will be somewhat improved, no change in toxicant levels is expected. Expected phenolic residues could possibly taint edible fish. Cadmium is not expected to occur in concentrations which would be acutely toxic to adult fish, however, it could be toxic to the more sensitive eggs and larvae. Mercury could possibly occur in concentrations which would be toxic to sensitive fish species. It is expected that the fisheries community will biomagnify all heavy metals. The expected mercury concentrations are such that biomagnification of this metal could reduce gamefish utility.

dd. Summary -- No substantial environmental improvements can be forseen after the institution of secondary level treatment for wastewater inputs. It must be pointed out, however, that without at least secondary treatment, increased wastewater flows would likely have a highly negative impact on the biota of Area III.

6) Merrimack River Estuary -- Since secondary treatment of wastewater removes biochemical oxygen demand and suspended solids, but provides little or no reduction of nutrients and various toxic materials, the overall impact of the projected increased waste loading of the Merrimack River on the Merrimack River Estuary, at the time of secondary implementation, will be negative. Direct discharge of secondary treated waste from Newburyport and Salisbury into the Estuary is expected to have a negative impact. Ammonia is likely to remain toxic for a

longer period of time due to the higher alkalinity of the estuarine water. Residual chlorine and chloramines will probably have toxic, sublethal effects on various estuarine organisms. Finally, chronic sublethal effects of heavy metals will have a deleterious effect on estuarine organisms.

2. Advanced Wastewater Treatment Alternatives (Figures 32-36)

Water Oriented Alternatives

The institution of any of the proposed wastewater treatment alternatives for the Massachusetts section of the Merrimack River basin would have a strong positive environmental impact. A detailed discussion explaining the rationale for evaluation of each of the alternatives is presented in Volume 2 in conjunction with the overall assessments. In the Merrimack River it can be expected that advanced wastewater treatment (AWT) will result in increased dissolved oxygen concentrations and reduced turbidity. Reactions of phytoplankton to the initiation of AWT is impossible to assess with any degree of certainty, but for evaluative purposes it was assumed the overall responses would be positive[1]. These factors combined with a reduction in heavy metal concentrations in water and sediments should allow increased diversity of benthic invertebrate fauna to include the more sensitive epifaunal forms such as mayfly and caddisfly larvae which are more available to sight feeding species of fish. Resident fish populations should also increase in diversity and evolve into a viable and utilizable warm-water fishery. This fishery would be typified by game fish such as largemouth bass and chain pickerel, and panfish such as yellow perch, pumpkinseed sunfish and bluegill. Forage fish species would also be expected to increase. It is likely that the anadromous American shad populations would be benefited by AWT alternatives. In the Concord River similar changes would be expected although to a lesser degree largely due to natural enrichment occurring there.

With regard to specific alternatives, the land oriented alternatives should be modified so that no discharge of secondary treated wastewater to the Merrimack River estuary be made. If estuarine discharge is contemplated at all it should be of AWT quality to remove the danger of toxic metal biomagnification.

[1]See "Algal Bioassays" under RECOMMENDATIONS FOR FURTHER STUDY.

All alternatives should replace chlorination with ozonation to eliminate chlorine, ammonia, and chloramine toxicity problems which, in general, are the only effluent problem parameters. With this modification, discharge to small tributary streams becomes more feasible. Finally, the wastewater management alternative chosen for implementation should be as decentralized as practicable to minimize local environmental impacts and the chance of major system impacts in the event of a plant malfunction. In their present form, Alternate 2 (Water Oriented Partially Decentralized) is the alternate considered to have the least negative environmental impact. The institution of any advanced wastewater treatment alternative will reduce both the amount of organic material and the toxic materials content of the affected river sediments.

The advanced wastewater alternatives 1-4 will primarily affect terrestrial ecosystems through sludge or sludge ash disposal via wetland or sanitary landfill operations. Adverse impacts to wetlands and to groundwater resources are more likely with sludges from advanced treatment processes due to the fact that more of the pollutants have been removed from the wastewater. It is believed that disposal of these sludges could result in both short and long-term disruptive impacts.

The utilization of land for the purpose of construction of treatment facilities will result in adverse impacts to existing terrestrial ecosystems within the project area. However, when considered on a regional basis, these impacts are negligible.

The primary differences in impacts between centralized vs decentralized schemes involves the differences in the quantities of sludge material that must be disposed of. Obviously larger quantities would be potentially more disruptive than smaller volumes. However, for the purposes of the present discussion no distinctions between centralization and decentralization are made.

Terrestrial Oriented Alternatives

At present, sufficient information is not available to accurately delineate specific aquatic environmental impacts of land oriented wastewater management alternatives. Eventually wastewaters applied to terrestrial ecosystems will reach surface water bodies through groundwater recharge. At such time however, the wastewaters will be sufficiently renovated, resulting in beneficial impacts to aquatic ecosystems.

Since specific land application sites are not designated in the proposed alternatives, detailed analysis of the terrestrial environmental impacts cannot be determined. Impacts from both SI and RI operations are based on the previously established assumptions regarding wastewater composition, application rates, and site conditions.

Potential environmental impacts of Alternatives 5 and 6 to specific components of both aquatic and terrestrial ecosystems are presented in Tables 75-76. From the viewpoint of both aquatic and terrestrial ecosystems, distinctions between alternatives 5 and 6 are not made.

The following interpretations of terrestrial impact assessment symbols apply to ecosystem components presented for land oriented alternatives.

Climate	*	Climatic changes occur as a result of increased evaporation rate and differences between air and wastewater temperatures, but these changes cannot be evaluated on the basis of positive, neutral or negative impacts.
	0	Impact is negligible (rapid infiltration) or limited to the area immediately surrounding the disposal site (spray irrigation).
Physiography	0	Careful choice of disposal site should eliminate the most likely physiographic hazard, that of soil erosion.
Soils	+	Wastewater effluent would function as a soil conditioner, increasing soil organic content; the ability of droughtly soils to retain moisture and certain nutrients, such as phosphates, would be improved.
	+[1]	Prolonged use of the same site may lead to plugging of soil pores and/or accumulation of toxic substances, such as heavy metals.
	0	Careful selection of a disposal site suited to the mode of application should eliminate potential drainage problems from becoming widespread.

Groundwater	+	Rapid infiltration. Areas experiencing acute lowering of the water table would be recharged. The recharge would be especially beneficial if water quality resulting from the dilution of percolate with natural groundwater meets drinking water standards.
	+	Spray irrigation. The reliability of this technique is renovating wastewater minimizes the potential for groundwater contamination (particularly with respect to nitrate).
	+[1]	Prolonged use of the same site increases the risk of widespread dissemination of wastewater contaminants (e.g. nitrate) into an aquifer, detracting from the value of the aquifer as a reserve water supply.
	0	Impact is limited to the area immediately surrounding the disposal site.
	-	Since dilution of percolate by natural groundwater is currently seen as a major factor in determining resultant water quality, groundwater quality would be poorest closest to the point of application.
Vegetation	+	Plant production would be stimulated by moisture and nutrients supplied by the wastewater. Cultivated crops should be chosen carefully for their suitability and contribution to renovation; natural plant communities would shift to moisture tolerant species.
	+[1]	Prolonged use of the same site may lead to accumulation of toxic substances (e.g. heavy metals) in plant tissues.
	0	Impact is limited to the area immediately surrounding the disposal site.
Birds & Mammals	+	Certain species (e.g. deer and cottontail rabbits) may gain food or shelter benefit from increased plant cover.

0 — Impact is negligible (rapid infiltration) or limited to the area immediately surrounding the disposal site.

3. Alternate 1. Water Oriented, Decentralized - Advanced Wastewater Treatment (see Figure 32, Table 71).

a) Physical

1) Concord River -- Increased water inputs will tend to stabilize summer low flows in the Concord River below the Billerica outfall. Such a flow stabilization will have a positive environmental impact on the river. This flow increase could possibly increase dissolved oxygen and reduce solar heating during periods of low flow. No significant impact on stream turbidity is expected.

2) Powwow River -- Increased water inputs will tend to stabilize summer low flows in the Powwow River. Such a flow stabilization will have a positive environmental impact and could possibly improve dissolved oxygen levels and reduce solar heating during periods of low flow. No significant impact on stream turbidity is expected.

3) Merrimack River, Area I - III and Estuary -- The magnitude of flows to be introduced are not of sufficient volume to noticeably impact the river or estuarine system.

b) Chemical

1) Concord River

aa. Primary Productivity -- No substantial impact is expected since the system is already highly enriched naturally.

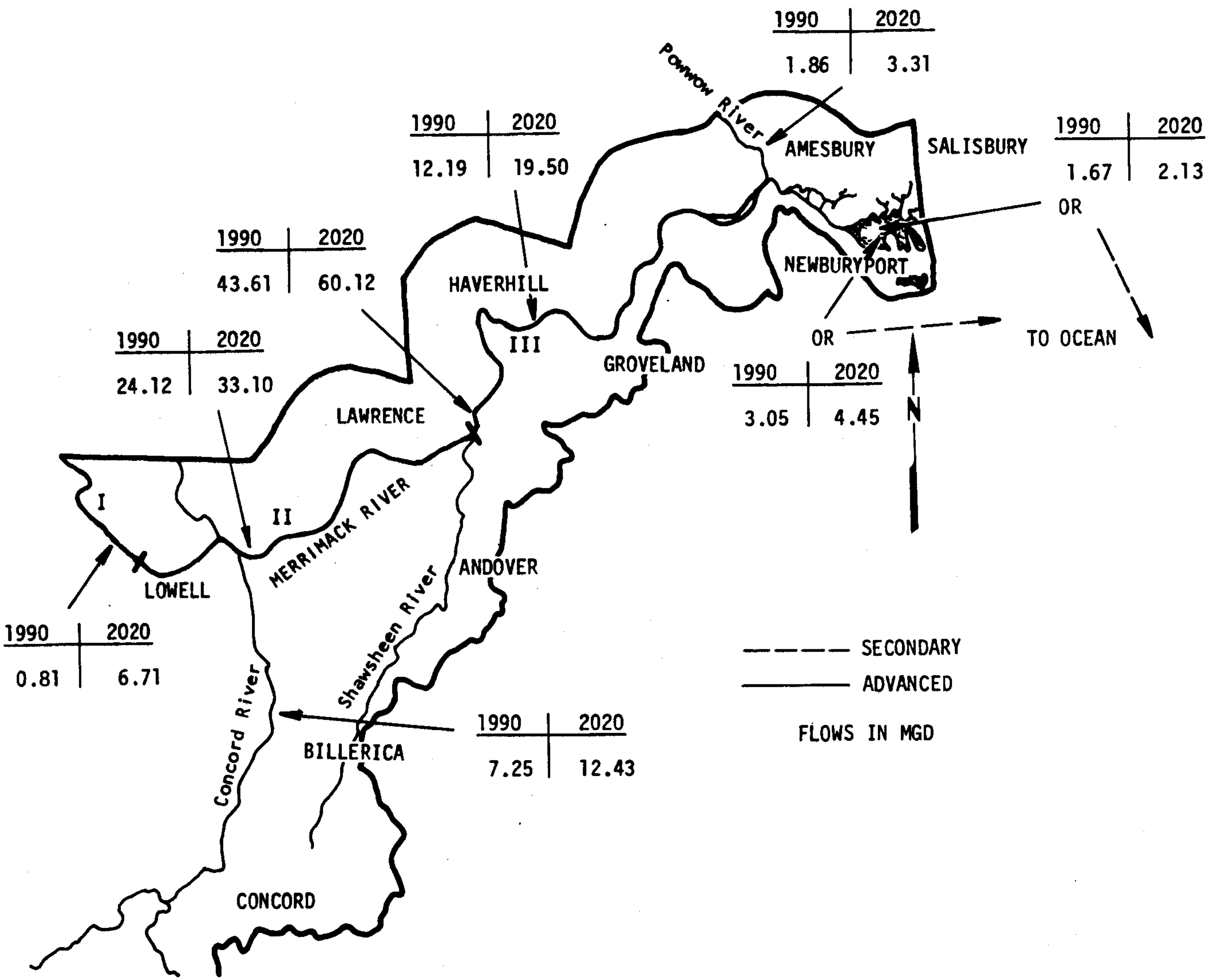

Figure 32. **Wastewater inputs to the aquatic ecosystem - Alternate 1. Water oriented decentralized.**

TABLE 71. POTENTIAL AQUATIC AND TERRESTRIAL IMPACTS OF WASTEWATER MANAGEMENT ALTERNATIVE I (WATER ORIENTED DECENTRALIZED)

AQUATIC

	1990						2020					
	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III	ESTUARY	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III	ESTUARY
Plankton	O	O	+	+	+	+	O	O	+	+	+	+
Aquatic Macrophytes	O	O	+	+	+	+	O	O	+	+	+	+
Invertebrates (Fish Food Organisms)	+	–	+	+	+	+	+	–	+	+	+	+
Fish	+	–	+	+	+	+	+	–	+	+	+	+

TERRESTRIAL

	TREATMENT FACILITIES		TREATMENT SLUDGES	
	1990	2020	1990	2020
Soil	– / O	– / O	– / O	– / O
Vegetation	– / O	– / O	– / O	– / O
Wildlife	– / O	– / O	– / O	– / O
Groundwater	O / O	O / O	– / O[1]	– / O[1]

[1]Long term effects may be negative

LOCAL / REGIONAL

bb. Invertebrates -- Removal of toxic metals from wastewater effluent will permit more sensitive invertebrate organisms to proliferate in the Concord River.

cc. Fish -- Removal of toxic metals from wastewater effluent will permit more sensitive fish (game fish) to proliferate in the Concord River.

dd. Summary -- Substantial improvement over existing conditions because of flow augmentation and removal of toxic materials. Toxicity problems of ammonia and residual chlorine will have some negative environmental impact, however.

2) Powwow River

aa. Primary Productivity -- Although some reduction of primary productivity is expected no substantial impact is predicted since the system is already highly enriched from natural sources.

bb. Invertebrates -- Removal of toxic metals from wastewater effluent will permit more sensitive invertebrate organisms to proliferate in the Powwow River. During periods of low flow, the wastewater discharge contemplated by this alternative will dominate the river flow. Under such conditions, it is likely that ammonia and residual chlorine will approach toxic levels.

cc. Fish -- Removal of toxic metals from wastewater effluent will permit more sensitive fish (game fish) to proliferate in the Powwow River. During periods of low flow, the wastewater discharge contemplated by this alternative will dominate the river flow. Under such conditions, it is likely that ammonia and residual chlorine will approach toxic levels in the Powwow River.

dd. Summary -- Substantial improvement over existing conditions because of flow augmentation and removal of toxic materials. Toxicity problems of ammonia and residual chlorine will have some negative environmental impact, however.

3) Merrimack River, Area I -- Only local effects will operate in this area. The effluent discharge (1990, 2020) is too small to substantially alter general water chemistry.

4) Merrimack River, Area II -- Local impacts will dominate. Some chance of ammonia and chlorine toxicity to invertebrates and fish during low flows.

5) Merrimack River, Area III -- Local impacts will dominate. Greater chance for ammonia and chlorine toxicity than in Area II due to tidal impoundment and heavier waste loading.

6) Merrimack River Estuary -- Only local impacts will operate. In general the addition of AWT effluent will result in an overall improvement in existing water quality.

c) Summary

Negative impacts will increase in 2020 over 1990 but not significantly. In general AWT would be expected to substantially improve existing conditions with only local negative impacts operating.

4. Alternate 2, Water Oriented, Partially Decentralized (see Figure 33, Table 72).

   a) Physical -- No substantial physical impact forseen on any stream -- would expect turbidity reduction in Merrimack River, Area III.

   b) Chemical

      1) Concord River -- Removal of wastewater discharges will have a positive impact.

         aa. Primary Productivity -- No substantial impact is expected since the system is naturally enriched. However, a slight positive impact would result from effluent removal from the river.

         bb. Invertebrates -- Removal of toxic materials input will permit more sensitive invertebrate organisms to proliferate in the Concord River.

         cc. Fish -- Removal of toxic materials input will permit more sensitive fish (game fish) to proliferate in the Concord River.

         dd. Summary -- An overall improvement in water quality is expected due to removal of existing Concord River effluents.

      2) Powwow River -- Removal of wastewater inputs will have positive impact.

         aa. Primary Productivity -- Although some reduction of primary productivity is expected no substantial impact is predicted since the system is already highly enriched from natural sources.

         bb. Invertebrates -- Removal of toxic materials will permit more sensitive invertebrate organisms to proliferate in the Powwow River.

         cc. Fish -- Removal of toxic materials will permit more sensitive (game fish) to proliferate in the Powwow River.

         dd. Summary -- Substantial improvement over existing conditions because of toxic materials removal.

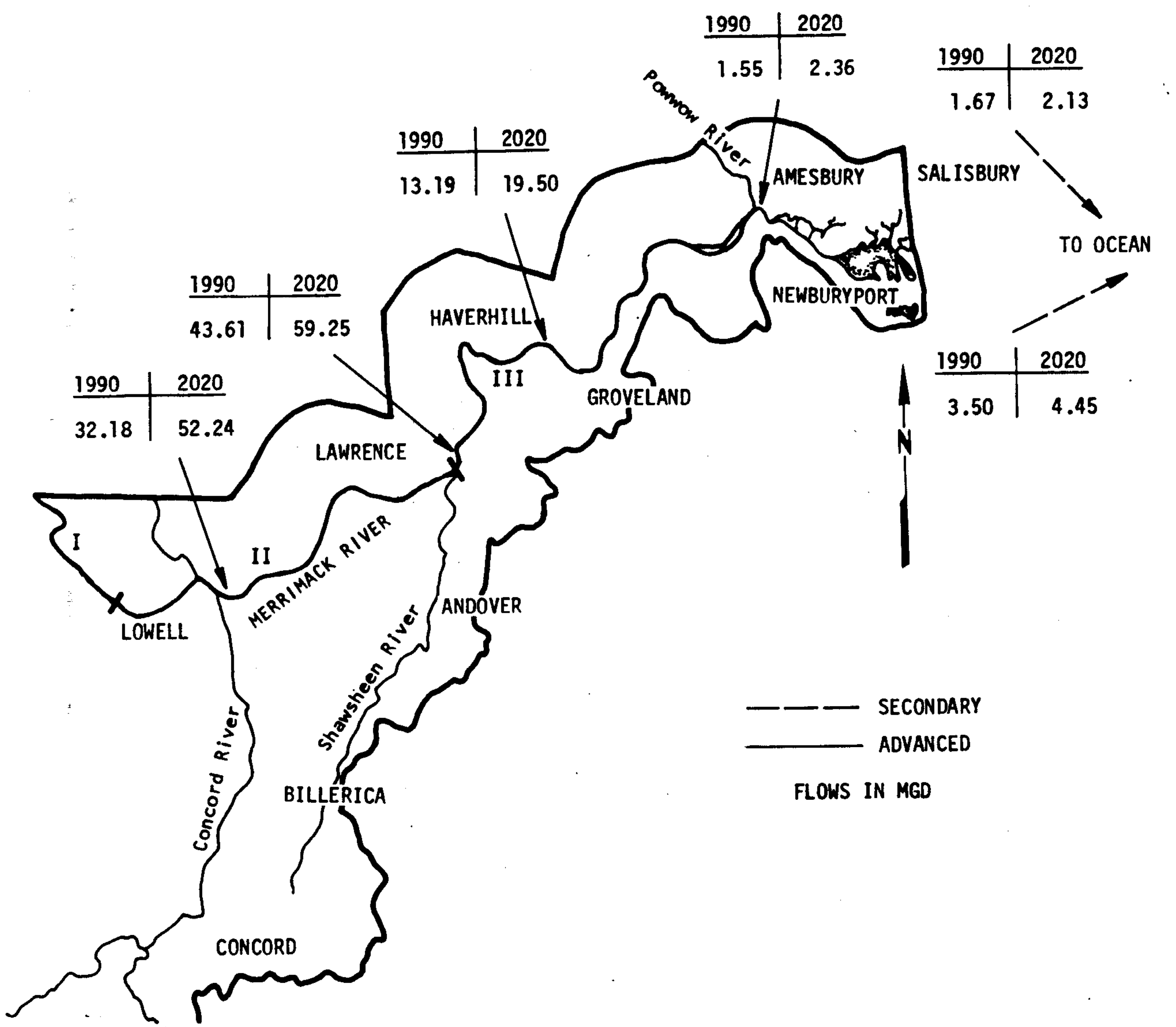

Figure 33. Wastewater inputs to the aquatic ecosystem - alternate 2. Water oriented partially decentralized.

TABLE 72. POTENTIAL AQUATIC AND TERRESTRIAL IMPACTS OF WASTEWATER MANAGEMENT ALTERNATIVE 2 (WATER ORIENTED PARTIALLY DECENTRALIZED)

AQUATIC

	1990						2020					
	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III	ESTUARY	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III	ESTUARY
Plankton	+	+	+	+	+	+	+	+	+	+	+	+
Aquatic Macrophytes	+	+	+	+	+	+	+	+	+	+	+	+
Invertebrates (Fish Food Organisms)	+	+	+	+	+	+	+	+	+	+	+	+
Fish	+	+	+	+	+	+	+	+	+	+	+	+

TERRESTRIAL

	TREATMENT FACILITIES		TREATMENT SLUDGES	
	1990	2020	1990	2020
Soil	- / O	- / O	- / O	- / O
Vegetation	- / O	- / O	- / O	- / O
Wildlife	- / O	- / O	- / O	- / O
Groundwater	O / O	O / O	- / O[1]	- / O[1]

[1]Long term effects may be negative

LOCAL / REGIONAL

3) Merrimack River Area I -- Removal of waste-water inputs will have a positive impact.

aa. Primary Productivity -- Removal of waste-water inputs should decrease primary productivity as a result of decreased nutrients inflows.

bb. Invertebrates -- Removal of toxic materials will permit more sensitive invertebrate organisms to proliferate in this section of the Merrimack River.

cc. Fish -- Removal of toxic materials will permit more sensitive fish (gamefish) to proliferate in this section the Merrimack River.

dd. Summary -- Substantial improvement over existing conditions because of toxic materials and nutrient reduction.

4) Merrimack River, Area II -- Local impacts will dominate. Some chance of ammonia and chlorine toxicity to invertebrates and fish during low flows.

5) Merrimack River, Area III -- Local impacts will dominate. Greater chance for ammonia and chlorine toxicity than in Area II due to tidal impoundment and heavier waste loading.

6) Merrimack River Estuary -- Removal of waste-water inputs will have a positive impact.

7) Summary -- Impacts will increase in 2020 over 1990, but no substantial change is foreseen -- generally expect substantial improvement over existing conditions.

5. Alternate 3, Water Oriented, Centralized (see Figure 34. Table 73).

a) Physical

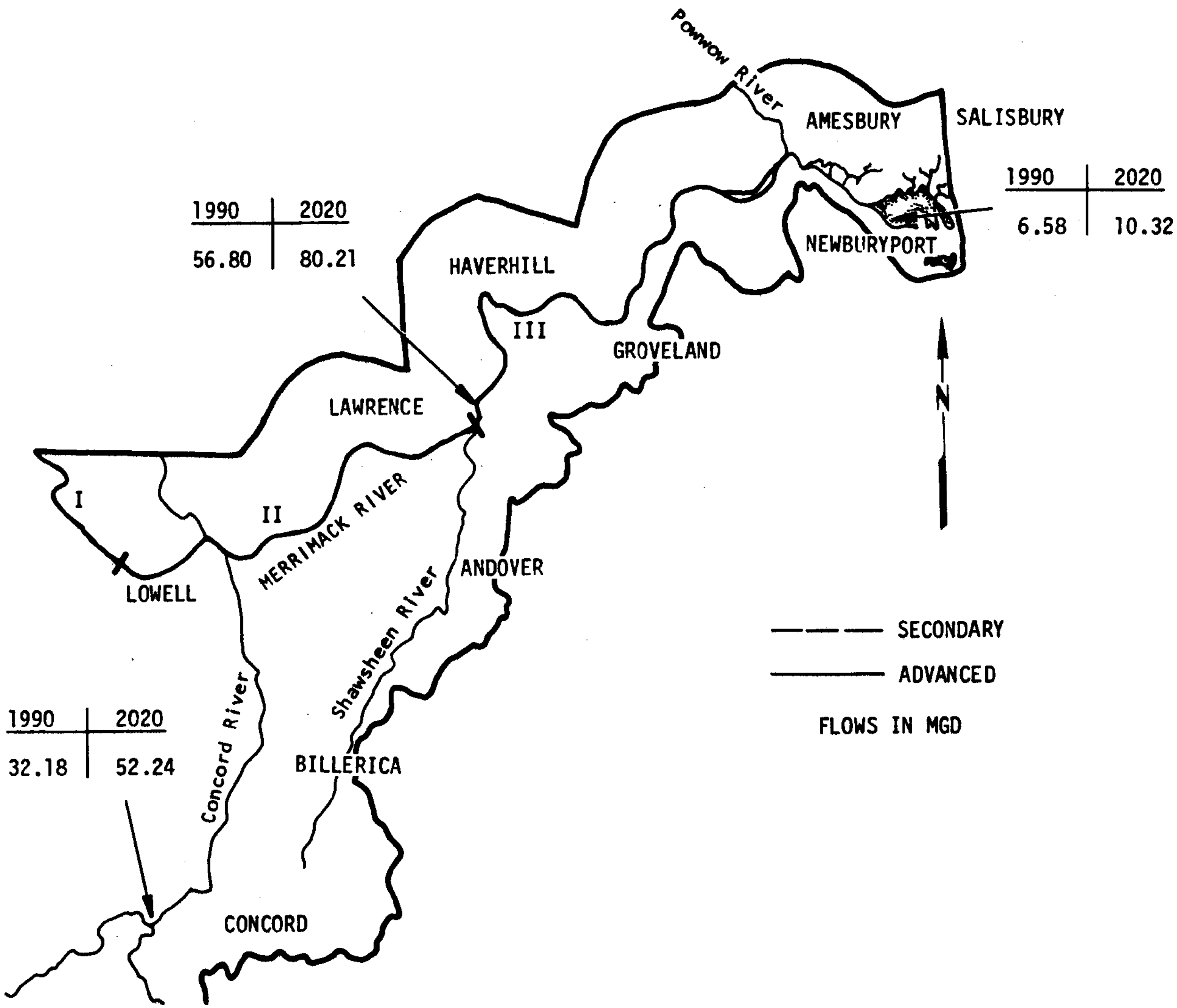

Figure 34. Wastewater inputs to the aquatic ecosystem - alternate 3. Water oriented centralized.

TABLE 73. POTENTIAL AQUATIC AND TERRESTRIAL IMPACTS OF WASTEWATER MANAGEMENT ALTERNATIVE 3 (WATER ORIENTED CENTRALIZED)

AQUATIC

	1990						2020					
	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III	ESTUARY	CONCORD[1] R.	POWWOW R.	AREA I	AREA II	AREA III	ESTUARY
Plankton	o	+	+	+	+	+	o	+	+	+	+	+
Aquatic Macrophytes	o	+	+	+	+	+	o	+	+	+	+	+
Invertebrates (Fish Food Organisms)	–	+	+	+	+	+	–	+	+	+	+	+
Fish	–	+	+	+	+	+	–	+	+	+	+	+

[1]Very substantial local impact

TERRESTRIAL

	TREATMENT FACILITIES		TREATMENT SLUDGES	
	1990	2020	1990	2020
Soil	– / o	– / o	– / o	– / o
Vegetation	– / o	– / o	– / o	– / o
Wildlife	– / o	– / o	– / o	– / o
Groundwater	o / o	o / o	– / o[1]	– / o[1]

[1]long term effects may be negative

LOCAL / REGIONAL

1) Concord River -- A substantial flow augmentation is expected which will tend to stabilize low summer flows in the Concord River. Such flow augmentation could possibly improve dissolved oxygen conditions and reduce solar heating in summer low flow periods. No substantial impact on turbidity is expected, however a slight increase might be expected.

2) Powwow River -- Since effluents are not located in in the Powwow River under this concept, a positive impact is expected in the form of reduced turbidity.

3) Merrimack River, Areas I, II, III, and Merrimack River Estuary -- No significant effect, with exception of lowered turbidity levels in Area III.

b) Chemical

1) Concord River

aa. Primary Productivity -- No substantial impact is expected since the system is already highly enriched naturally.

bb. Invertebrates -- Removal of toxic metals from wastewater effluent will permit more sensitive invertebrate organisms to proliferate in the Concord River. During periods of low flow, the wastewater discharge contemplated by this alternative will dominate the river flow. Under such conditions, it is likely that ammonia and residual chlorine will approach toxic levels in the Concord River below the outfall at Concord.

cc. Fish -- Removal of toxic metals from wastewater effluent will permit more sensitive fish (game fish) species to proliferate in the Concord River. During periods of low flow, the wastewater discharge contemplated by this alternative will dominate the river flow. Under such conditions, it is likely that ammonia and residual chlorine will approach toxic levels in the Concord River below Concord.

dd. Summary -- Substantial improvement over existing conditions should result because of flow augmentation and removal of toxic materials. Toxicity problems of ammonia and residual chlorine will have some negative environmental impact, however.

2) Powwow River -- Removal of wastewater effluent will have a positive environmental impact.

3) Merrimack River Area I -- Removal of wastewater effluent will have a positive effect.

4) Merrimack River, Area II -- Local impacts in the vicinity of the Concord River mouth. No substantial environmental impacts are expected.

5) Merrimack River, Area III -- Local effects will dominate. However, there is some chance for ammonia and chlorine toxicity during periods of low flow.

6) Merrimack River Estuary -- Discharge of AWT effluent to the Estuary will have primarily a localizing impact.

7) Summary -- Impacts will increase in 2020 over 1990, however, no substantial change is forseen. A substantial improvement over existing conditions may be expected.

6. Alternate 4, Water Oriented, Regional (see Figure 35, Table 74).

a) Physical

1) Concord River -- Removal of wastewater input will have a positive environmental effect as a result of reduced turbidity.

2) Powwow River -- Removal of wastewater input will have a positive environmental effect as a result of reduced turbidity.

3) Merrimack River,Area I -- Removal of wastewater inputs will have a positive environmental impact.

4) Merrimack River, Area II -- Removal of wastewater inputs will have a positive environmental impact.

5) Merrimack River, Area III -- There will be a very large local impact at the Lawrence outfall, Because of increased effluent values and decreased distance for river assimilation, the environmental impacts of this alternate will be increased over other alternates,

6) Merrimack River Estuary -- Ingestion of AWT effluent is not expected to have a negative impact and improved water quality should have an overall positive impact.

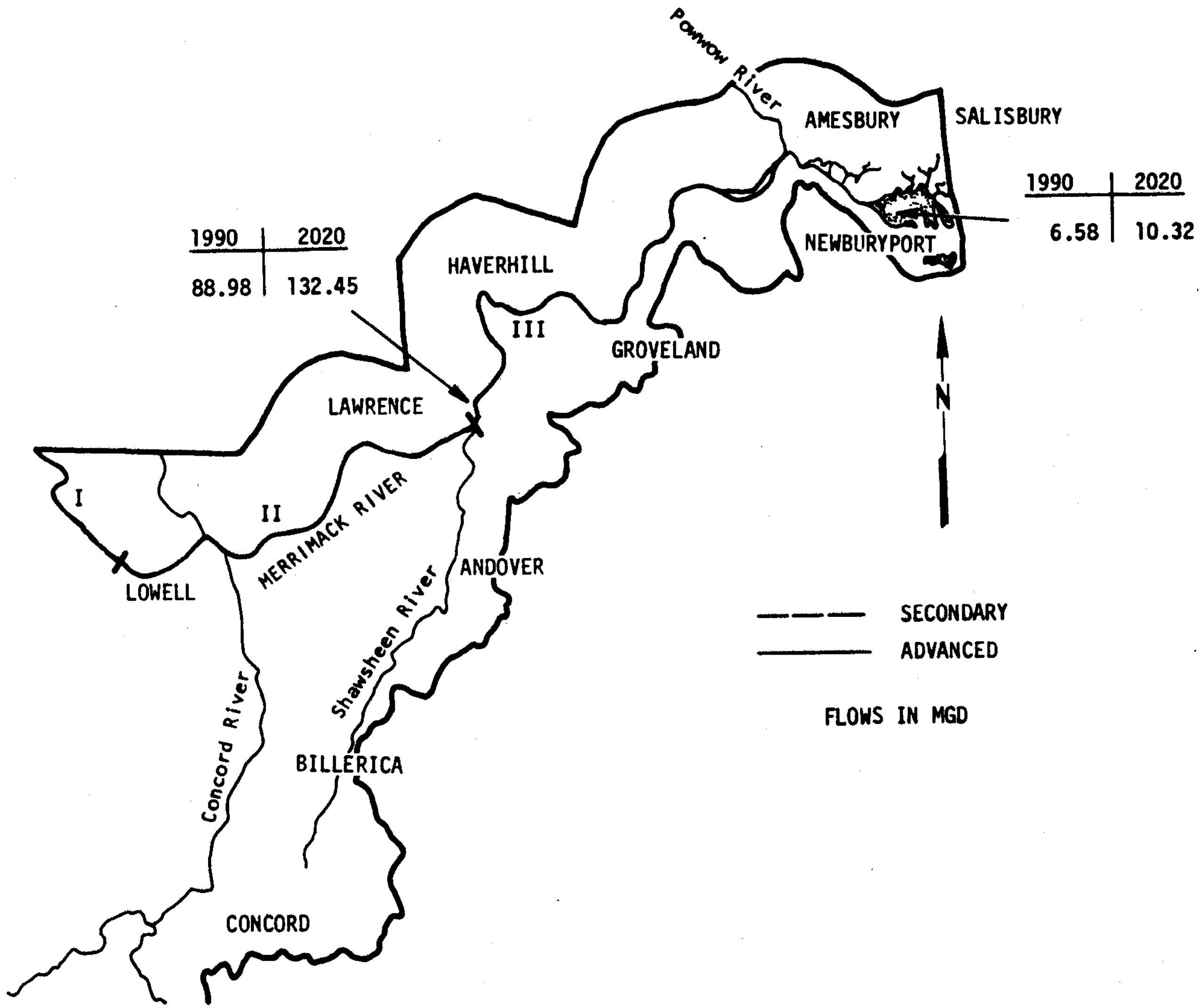

Figure 35. Wastewater inputs to the aquatic ecosystem - alternate 4. Water oriented regional.

TABLE 74. POTENTIAL AQUATIC AND TERRESTRIAL IMPACTS OF WASTEWATER MANAGEMENT ALTERNATIVE 4 (WATER ORIENTED REGIONAL)

AQUATIC

	1990 CONCORD R.	1990 POWWOW R.	1990 AREA I	1990 AREA II	1990 AREA III[1]	1990 ESTUARY	2020 CONCORD R.	2020 POWWOW R.	2020 AREA I	2020 AREA II	2020 AREA III[1]	2020 ESTUARY
Plankton	+	+	+	+	O	+	+	+	+	+	O	+
Aquatic Macrophytes	+	+	+	+	O	+	+	+	+	+	O	+
Invertebrates (Fish Food Organisms)	+	+	+	+	-	+	+	+	+	+	-	+
Fish	+	+	+	+	-	+	+	+	+	+	-	+

[1]Very substantial local impact

TERRESTRIAL

Each cell: LOCAL / REGIONAL

	TREATMENT FACILITIES 1990	TREATMENT FACILITIES 2020	TREATMENT SLUDGES 1990	TREATMENT SLUDGES 2020
Soil	- / O	- / O	- / O	- / O
Vegetation	- / O	- / O	- / O	- / O
Wildlife	- / O	- / O	- / O	- / O
Groundwater	O / O	O / O	- / O[1]	- / O[1]

[1]long term effects may be negative.

LOCAL / REGIONAL

7) Summary -- As with other alternates this alternate will significantly improve existing water quality, however there will be a significant localized impact in Area III.

b) Chemical

1) Concord River, Merrimack River Areas I and II -- Removal of wastewater effluent will have a positive chemical impact as a result of the lowering of nutrients and toxicant concentrations.

2) Merrimack River Areas III -- There will be a large local impact at the Lawrence outfall. Because of increased effluent discharge and decreased discharge and decreased distance for river assimilation of chlorine and ammonia, potential negative impacts are greater with this alternative than other AWT concepts.

3) Merrimack River Estuary -- Advanced wastewater treatment treatment will result in an overall positive impact on estuarine water quality.

4) Summary -- As with other alternatives this concept will significantly improve existing water quality although a localized negative impact will be possible in Area III.

7. Alternates 5 and 6 -- Aquatic Portion (see Figure 36, Tables 75 & 76).

   a) Physical

      1) Concord River, Powwow River, Merrimack River Areas I and II -- Absence of effluents will result in a positive impact on the affected portions of river.

      2) Merrimack River Areas I, II, III, and Merrimack River Estuary -- No significant environmental impact.

   b) Chemical

      1) Concord River -- Removal of wastewater input will have a positive environmental effect.

      2) Powwow River -- Removal of wastewater input will have a positive environmental impact.

      3) Merrimack River Area I, and II -- Removal of wastewater input will have a positive effect.

      4) Merrimack River Area III -- Input of AWT effluent at Lawrence will have primarily a local effect. During periods of low flow, it is possible that ammonia and chlorine toxicity will be present.

      5) Merrimack River Estuary -- The overall impact of these alternatives on the estuary will be positive because of decreased water loading. However, it is not felt that introduction of secondary waste effluent to the estuary is environmentally sound. Ammonia will likely remain toxic for a longer period of time due to the higher alkalinity of the estuarine water. Residual chlorine and chloramines will probably have toxic sublethal effects on various estuarine organisms. Finally, chronic sublethal effects of some heavy metals will have a deleterious effect on estuarine organisms.

      6) Summary -- Water quality in most areas will be improved under this alternate, however the presence of a secondary treatment plant discharging to the estuary is not felt to be environmentally sound.

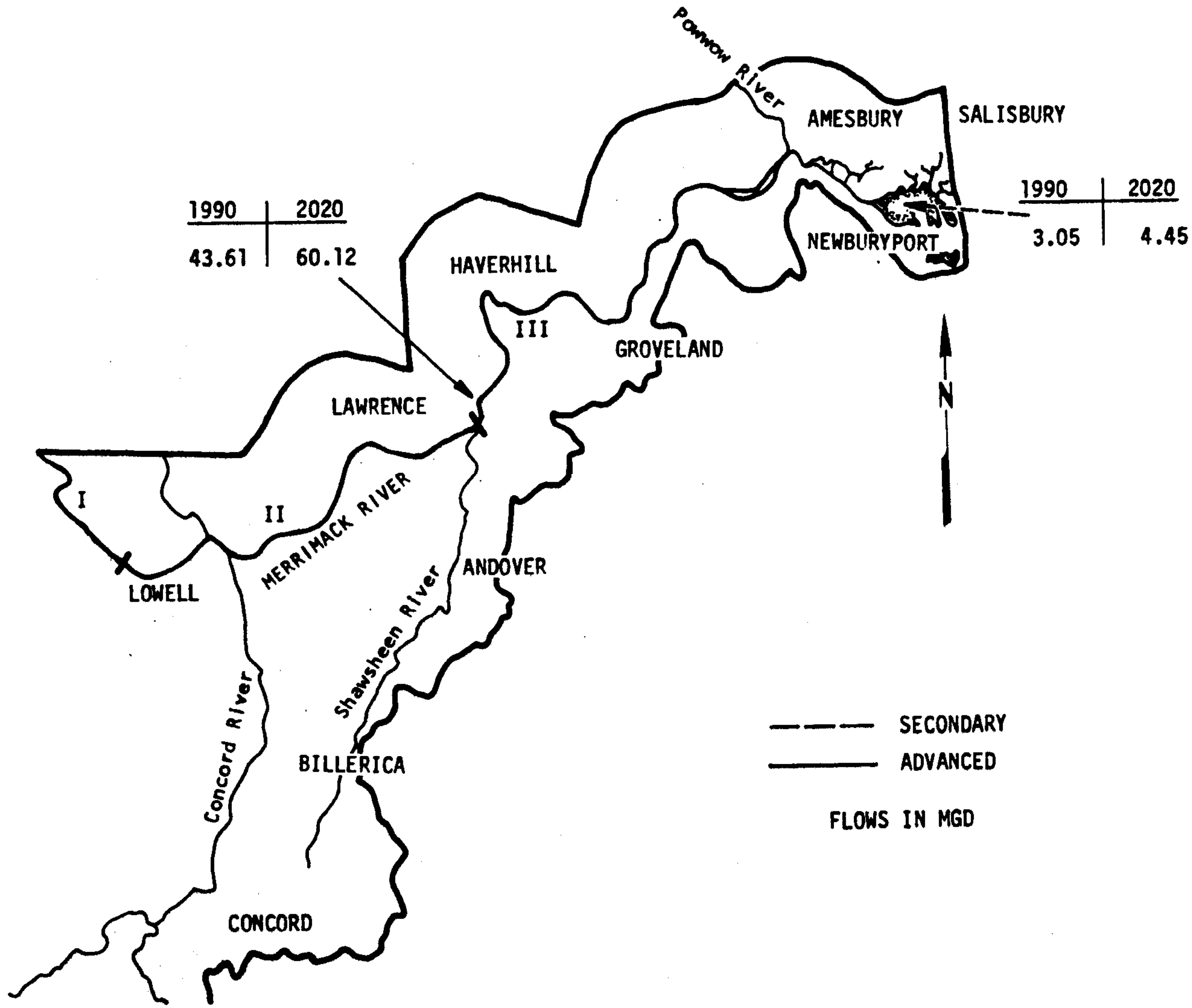

Figure 36. Wastewater inputs to the aquatic ecosystem - alternatives 5 and 6 land oriented system.

TABLE 75. POTENTIAL AQUATIC AND TERRESTRIAL IMPACTS OF WASTEWATER MANAGEMENT ALTERNATIVE 5 (LAND - DECENTRALIZED)

AQUATIC

	1990						2020					
	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III	ESTUARY	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III[1]	ESTUARY
Plankton	+	+	+	+	+	+	+	+	+	+	+	+
Aquatic Macrophytes	+	+	+	+	+	+	+	+	+	+	+	+
Invertebrates (Fish Food Organisms)	+	+	+	+	+	+	+	+	+	+	+	+
Fish	+	+	+	+	+	+	+	+	+	+	+	+

[1] Substantial local impact

TERRESTRIAL

	SI		RI	
	1990	2020	1990	2020
Climate	* / O	* / O	O / O	O / O
Physiography	O / O	O / O	O / O	O / O
Soils	+ / O	+[1] / O	+ / O	+[1] / O
Groundwater	+ / O	+ / O	- / +	- / +[1]
Vegetation	+ / O	+[1] / O	+ / O	+ / O
Birds & Mammals	+ / O	+ / O	O / O	O / O

*changes will result which cannot be classified as positive, neutral or negative

[1]long term effects may be negative

LOCAL / REGIONAL

TABLE 76. POTENTIAL AQUATIC AND TERRESTRIAL IMPACTS OF WASTEWATER MANAGEMENT ALTERNATIVE 6 (LAND - CENTRALIZED)

AQUATIC

	1990						2020					
	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III	ESTUARY	CONCORD R.	POWWOW R.	AREA I	AREA II	AREA III[1]	ESTUARY
Plankton	+	+	+	+	+	+	+	+	+	+	+	+
Aquatic Macrophytes	+	+	+	+	+	+	+	+	+	+	+	+
Invertebrates (Fish Food Organisms)	+	+	+	+	+	+	+	+	+	+	+	+
Fish	+	+	+	+	+	+	+	+	+	+	+	+

[1]Substantial local impact

TERRESTRIAL

	SI		RI	
	1990	2020	1990	2020
Climate	* / O	* / O	O / O	O / O
Physiography	O / O	O / O	O / O	O / O
Soils	+ / O	+[1] / O	+ / O	+[1] / O
Groundwater	+ / O	+ / O	– / +	– / +[1]
Vegetation	+ / O	+[1] / O	+ / O	+ / O
Birds & Mammals	+ / O	+ / O	O / O	O / O

*changes will result which cannot be classified as positive, newtral or negative

[1]long term effects may be negative

LOCAL / REGIONAL

VI. RECOMMENDATIONS FOR FURTHER STUDY

During the review of existing water quality, sedimentary, and biologic data for the Massachusetts section of the Merrimack River Basin, four major problems became apparent: 1) existing data were limited primarily to the summer months, 2) the number of parameters measured was extremely limited, 3) no replicate samples were taken, and 4) methods of sample collection, analyses, and data presentation were not standardized. In order to make future studies more meaningful, a regional authority should conduct and report the results using procedures which adhere to established national or, preferably, international standards, such as those described in "Biological Field and Laboratory Methods" (EPA, 1973) or International Biological Programme (IBP) Handbooks, published by Blackwell Scientific Publications, Oxford and Edinburgh. In addition, sampling points should be located such that the amount of information per unit of sampling effort can be maximized. To attain this goal, it is recommended that impounded areas on the rivers in question be emphasized in any sampling effort since they respond strongly to abiotic inputs and serve as "sinks". Also the Merrimack River Estuary should be emphasized due to its importance as a river terminus of the river system and an area of biological productivity. All future studies should be conducted on at least a seasonal basis so that the effect of a wide range of ambient environmental conditions may be experienced.

The types of studies needed to adequately assess the effect of regional wastewater management alternatives are listed in Table 77, in order of descending priority; estimated costs, also included, were established on the basis of professional judgement and do not represent a detailed itemization of expenses.

A. NEW APPROACHES

1. Dye Studies

Rhodamine dyes have been used successfully as tracer materials to determine the natural mixing and dilution of treatment plant effluents. Information provided by such a dye study relates to the flushing rate of the body of water, the ultimate fate of the effluent, and the concentration of the effluent in space and time.

A fluorescent dye is discharged from a calibrated fluid metering pump at the proposed discharge location and the resulting plume is monitored using a commercial fluorometer to detect the fluorescence. The fluorometers used are especially modified for full-flow continuous sampling from either stationary or moving craft. By

TABLE 77. SUMMARY OF RECOMMENDED STUDIES AND APPROXIMATE COSTS, BY ORDER OF PRIORITY

STUDY	MINIMUM RECOMMENDED LEVEL OF FUNDING ($)
Dye Study	
1. Freshwater Streams	10,000[1]
2. Estuary and Coastal	30,000[1]
Algal Bioassay	45,000
Anadromous Fish Bioassay	______[2]
Finfish Toxic Metal Content	80,000
Sediment Chemistry	75,000
Water Quality Monitoring	50,000[3]

[1]Per treatment plant outfall

[2]Discussions with specialists indicates that there presently exists no real basis for an accurate cost estimate

[3]Based on non-continuous sampling for four sampling periods during one year

monitoring the concentration of the dye in the water, it is possible to determine the amount of dilution due to tidal and other mixing processes at a given place and time in the tidal cycle. Isopleths of dilution may then be constructed to allow determination of the concentration of any constituent of the effluent at affected locations at any phase in the tidal cycle. Additional information can be obtained from the "decay" of the dye after the dye metering pump is turned off, since the amount of time required for the dye to be removed by natural processes is related to the flushing rate of the body of water in question.

2. Algal Bioassay

Some of the streams under consideration (e.g., the Merrimack River) carry heavy loads of toxicants. Since the streams in question may also carry heavy nutrient loads, to which even the more advanced sewage treatment processes contribute, removal of toxicants (as may be required by strict pollution control standards) could lead to an increase in algal productivity, rather than a decrease as would be desired. The specific requirements and responses of local algal populations are most properly addressed by conducting an algal bioassay. This interpretive technique would involve placing a water sample containing a known concentration of native algae into a series of flasks containing various nutrient media (some flasks will contain the suspect river water, others will be free of toxicants, etc.). After a period of incubation, changes in standing crop are determined by counting plant cells. Chlorophyll *a* determinations may also be used to determine standing crop. Conceivably, the experiments could demonstrate that stringent removal of certain nutrients need only be required during a portion of the year, to control algal blooms.

3. Anadromous Fish Bioassays[1]

Bioassay studies should be undertaken on both the Atlantic salmon[2] and the American shad to determine the level of wastewater

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[1],[2]Dr. Robert Lennon, University of Maine (pers. comm., 1974), has indicated that any bioassay of this nature would have to be conducted with existing apparatus because of the sophistication of the equipment needed, and that Atlantic salmon are not readily available in the quantity needed for bioassay studies. He suggested that rainbow trout be used instead as a good representative of the Salmonidae.

management required to sustain a viable fishery for both species in the Merrimack River Basin. Such a study should address itself not only to acute toxicity, but also to the problems of avoidance, by adults and young, of certain water quality conditions, and the chronic sub-lethal effects of various substances of the American shad.

B. SUPPLEMENTAL INFORMATION

1. Tissue Concentration of Toxic Metals

Toxic metal content in the biosphere is of major concern in an area of heavy industrialization and urbanization. A survey should be made of all major fish and shellfish species (in both fresh and salt water) with respect to tissue content (body burden) of metallic elements (especially, mercury, lead, zinc, cadmium, chromium, nickel and copper).

2. Sediment Chemistry

Sediments are both major repositories and sensitive indicators of many water borne constituents (e.g., organics and heavy metals). Studies should be undertaken to improve the understanding of sediment chemistry in the Merrimack River Basin and Estuary. At present there are limited data on bottom sediments from this area. Knowledge of toxic metal concentrations is incomplete.

3. Water Quality

A thorough, comprehensive water quality sampling program should be conducted prior to the start-up of any wastewater management alternative, and should be continued after the institution of a wastewater treatment alternative. Such a study would provide important data on the effectiveness of the wastewater management alternative implemented. This information would be of great value to future wastewater management planners.